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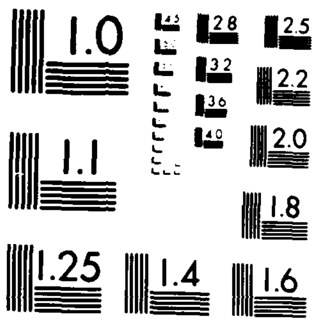

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Alaska Loran C Probe Test Results

Robert Erikson
Jean Evans
Mark Dickinson
Thomas Wisser
Martin Wortham

September 1987

DOT/FAA/CT-TN87/23

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16. Abstract

This report describes a flight test probe into Alaska to determine the extent of usable signals in space from Loran C stations Port Clarence, Narrow Cape, and Tok, Alaska. Flight measurements indicated adequate signal strength exists from the three Loran C stations over the routes flown. Therefore, it is feasible to dual rate Port Clarence as a new secondary in the Gulf of Alaska Loran C chain. Dual rating Port Clarence will increase the area where Loran C navigation is possible by providing proper chain structure. This largely increased area will be located in the middle to southern interior of Alaska.

The tests were conducted in the summer of 1985 and in the winter of 1985/86.

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EXECUTIVE SUMMARY

This report describes a flight test probe into Alaska to determine the extent of usable signals in space from Loran C stations Port Clarence, Narrow Cape, and Tok, Alaska. Flight measurements indicated adequate signal strength exists from the three Loran C stations over the routes flown. Therefore, it is feasible to dual rate Port Clarence as a new secondary in the Gulf of Alaska Loran C chain. Dual rating Port Clarence will increase the area where Loran C navigation is possible by providing proper chain structure. This largely increased area will be located in the middle to southern interior of Alaska.

The tests were conducted in the summer of 1985 and in the winter of 1985/86.

INTRODUCTION

OBJECTIVE.

The objective of this project was to investigate the extent of usable signals in space between Loran C stations Port Clarence, Narrow Cape, and Tok, Alaska, in order to determine the feasibility of dual rating Port Clarence to provide additional Loran C coverage in Alaska.

BACKGROUND.

The Federal Aviation Administration (FAA) has designated funds in fiscal year 1987 budget to allow the United States Coast Guard (USCG) to dual rate Loran C station Port Clarence, Alaska. The station would then function as a new secondary in the Gulf of Alaska Loran C Chain. This would be in addition to its current function as the Yankee (Y) secondary in the North Pacific Loran C Chain.

An FAA analysis indicated that Loran C coverage would be increased by approximately 93,000 square miles if Port Clarence is added to the Gulf of Alaska Chain. This additional coverage would provide service to 98 percent of the population of Alaska and 93 percent of the state's airports.

Loran C is a pulsed, low frequency, 100 kilohertz (kHz), hyperbolic navigation system. Loran C receivers convert signals from a master station and at least two secondaries into time differences. These are used to derive a geodetic position. Loran C ground wave signals provide coverage at low altitudes and in remote regions.

Prediction of accurate signal-to-noise ratio (SNR) is difficult in Alaska due to the low ground conductivity. SNR is calculated from field strength and atmospheric noise. The calculation of field strength and noise as a function of distance from the Loran C transmitter is difficult to determine and is explained in the following paragraphs.

In close proximity to a Loran C transmitter, differences in conductivities have little effect on the attenuation. As the distance to a transmitter increases, the effect of various ground conductivities on field strength becomes more pronounced. The attenuation of field strength also becomes more sensitive to ground conductivity as the conductivity decreases. Ground conductivities are lower in Alaska than in the conterminous United States. Permafrost has a very low conductivity and is prevalent in large areas of Alaska and Canada. Therefore, prediction of SNR without measured data could be inaccurate.

To justify expending funds to dual rate Port Clarence it was necessary to determine if SNR values from the three stations are sufficient for Loran C receiver acquisition and track. The USCG had only limited measured field strength data in the interior of Alaska to use in predicting SNR values in the area of interest. Additional data were needed throughout the predicted increased coverage area. While the use of ground measured data would have provided long term measurements with high quality receivers, the many points required to determine coverage and the logistics involved made this method impractical. The use of flight measurements would provide data over a larger geographic area in a shorter period of time but would only provide instantaneous measurements. It was

decided that flight measurements would be the best method to use in obtaining the needed data. To obtain an estimate of the extreme conditions, flights were conducted during the summer and the winter.

Of concern was the possibility that field strength and SNR measured in flight would be better than measured on the ground. Altitudes of 15000 feet and above were flown for fuel efficiency and in order to satisfy minimum en route altitude requirements. To address the effect of altitude on field strength measurements, special descending spiral flight patterns were conducted in the Fairbanks area.

In mountainous regions such as Alaska, the mountains may reradiate the Loran C signal over a distance of several hundred kilometers. Reradiation of the Loran C signals can cause cycle acquisition and tracking problems. In-flight monitoring of Loran C pulse shapes were conducted to look for this condition.

This report addresses the signal quality of the Loran C signals between Port Clarence, Narrow Cape, and Tok based on flight data. Justification for dual rating Port Clarence can be based on these signal quality measurements.

RELATED DOCUMENTATION.

1. Till, Robert D., Helicopter Global Positioning System Navigation with the Magnavox Z-Set, FAA Technical Center, Technical Note DOT/FAA/CT-TN83/03, August 1983.

2. Loran C Engineering Course, U.S. Coast Guard Academy, New London, Connecticut.

3. Wild Goose Association, Loran C System Characterization, WGA Publication No. 1/1976, September 1976.

4. Till, Robert D., and Erikson, Robert, Alaska Loran C Probe Test Plan, FAA Technical Center, Technical Note, DOT/FAA/CT-TN85/51, September 1985.

EQUIPMENT AND DATA COLLECTION

DATA ACQUISITION SYSTEM.

The FAA Technical Center's Convair CV-580 aircraft was equipped with five airborne Loran C receivers: Teledyne TDL-711, Micrologic ML-4000, Texas Instruments TI-9000, and two Advanced Navigation ONI-7000 units. All units were production models. The ONI-7000 receiver was primarily used for the flight tests. Other receivers were used for additional information when needed.

A Norden militarized PDP 11/34M computer was used to collect the data. The data were recorded on a Miltope 9-track tape recorder. A Technical Center designed aircraft systems coupler (ASC) was used to interface the Loran C receivers, aircraft state sensors, and position reference system to the Norden computer. Figure 1 is a block diagram of the system. Data recorded on the 9-track tape are presented in table 1.

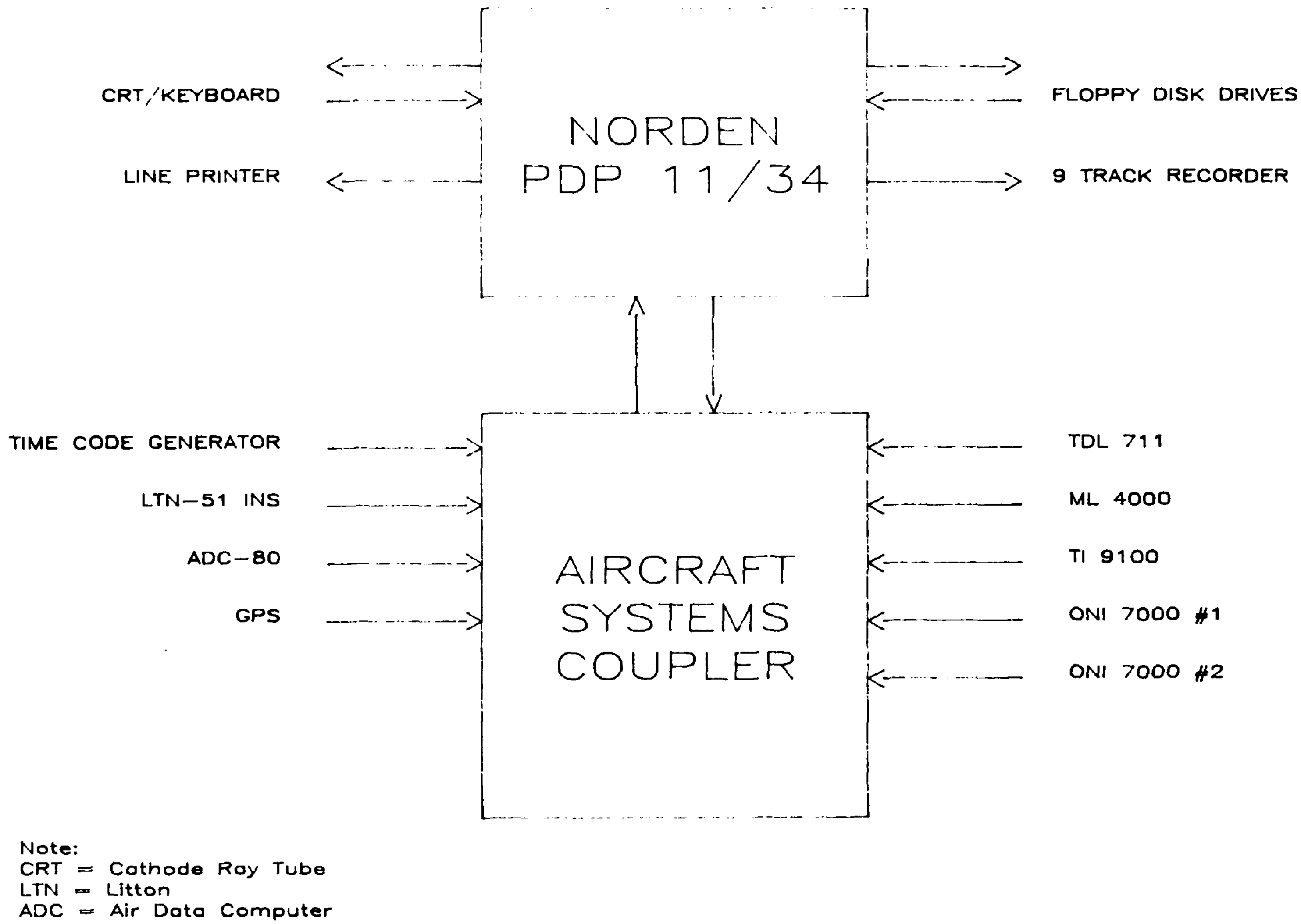


FIGURE 1. DATA COLLECTION SYSTEM

TABLE 1. RECORDED DATA

Aircraft Sensors and Time

Time:	Hours, minutes, seconds
LTN-51 INS:	Present position, heading, track angle, ground speed
ADC-80:	True airspeed, altitude
CDI:	Analog CDI
GPS:	Present position, velocities, and time

Loran C Receivers Recorded

	TDL-711	ML-4000	ONI-7000	TI-9100
Present Position Lat/Long	x	x	x	x
Station Status	-	M + 5	8	-
Station SNR's	M + 3	M + 5	8	-
Time Differences	2	2	8 TOA	-
ECD's	M + 3	-	8	-
To Waypoint Lat/Long	x	x	x	x
From Waypoint Lat/Long	x	x	-	x
Crosstrack Error	x	x	x	x
Ground Speed	-	x	x	x
Distance to Go	x	x	x	x
Front Panel Switch Setting	-	x	x	-
En Route/Approach	-	-	x	-
Annunciator Lamps	-	-	x	-
Receiver Status	x	-	x	x
Grid Reference	-	-	x	-
Bearing to Waypoint	-	-	x	x
Desired Track	-	-	x	x
Estimated Time En Route	-	-	x	x
Notch Filter Setting	-	-	x	-
Secondary Phase Delay	-	-	x	-
Triad in Use	-	-	x	-
Station Field Strength	-	-	x	-

Note:

LTN = Litton
INS = Inertial Navigation System
ADC = Air data computer
CDI = Course deviation indicator
GPS = Global positioning system
SNR = Signal-to-noise ratio
ECD = Envelope-to-cycle difference
x = Data present in digital output
M = Master
8 = Receiver can track up to 8 stations in the wide open mode
TOA = Time of arrival

The ONI-7000 Loran C receiver was configured to automatically select/deselect chains and stations. This method allowed the receiver to track the stations of interest, Tok, Narrow Cape, and Port Clarence, which happened to be in two different chains. The data collection system sampled and recorded the Loran C data and aircraft parameters every 10 seconds. The exception to this was that barometric altitude from the air data computer was recorded every second. Global Positioning System (GPS) data were recorded as available (nominally every 1.2 seconds).

In-flight printouts were generated every 30 seconds. Time, Inertial Navigation System (INS) position, and the differences in position between the INS and the respective Loran C and GPS receivers were displayed to the user.

POSITION REFERENCE SYSTEM.

A GPS receiver, the Magnavox Z-set (see Related Documentation No. 1) provided the primary aircraft position reference. The GPS accuracy is predicted to be better than 100 meters 2 distance root mean squared (drms).

SPECTRUM ANALYZER/OSCILLOSCOPE.

The Loran C spectrum was observed using a Tektronix 7L5 spectrum analyzer scope plug-in. Monitoring of Loran C pulses for possible reradiation was accomplished using a Tektronix 7A26 dual trace amplifier and 7B53 dual time base scope plug-ins. The desired scope plug-ins were installed as needed in a Tektronix R7603 mainframe oscilloscope which was permanently installed in the Technical Center CV-580. The signals were received using a Bayshore UPS-95 antenna and coupler.

TEST PROCEDURES

Test probe flights into Alaska were conducted along the route segments listed in table 2. The route waypoint locations are listed in table 3 and depicted in figure 2. While in the vicinity of large mountains the Loran C radio frequency (RF) signal was observed for possible reradiated Loran C signals. The field strength and atmospheric noise of Loran C stations Narrow Cape, Tok, and Port Clarence were monitored while flying along all segments.

In the vicinity of Fairbanks, Alaska, spiral descents to near ground level were conducted on the September 10 and 11 flights to collect data to determine the effect of altitude upon the Loran C field strength signal.

DATA REDUCTION

ANTENNA CALIBRATION VALUES.

The objective of this project was to evaluate Loran C signal coverage and to compare seasonal data. It was necessary to determine the true field strength to evaluate the Loran C signal coverage. To meet this objective it was necessary to obtain a calibration factor to adjust measured field strength data to obtain true field strength.

TABLE 2. FLIGHT SEGMENTS

Date		Route	Date		Route
9/9/85	Takeoff	Anchorage	2/16/86	Takeoff	Anchorage
	Start data	Tok		Refuel	Galena
		Port Clarence		Start data	Point 4
	Stop data	Point 3			Port Clarence
	Touchdown	Nome		Stop data	South
				Touchdown	Anchorage
9/10/85	Takeoff	Nome	2/17/86	Takeoff	Anchorage
	Start data	Point 3		Start data	South
		South			Tok
		Tok		Stop data	Point 4
	Stop data	Point 2		Touchdown	Fairbanks
	Collect spiral test data				
	Touchdown	Fairbanks			
9/11/85	Takeoff	Fairbanks	2/18/86	Takeoff	Fairbanks
	Start data	Point 2		Start data	Point 2
		Port Clarence		Stop data	Point 4
		North		Refuel	Galena
	Stop data	Point 1		Start data	Point 4
	Collect spiral test data				Port Clarence
	Touchdown	Fairbanks			North
				Stop data	Point 1
				Touchdown	Fairbanks
9/12/85	Takeoff	Fairbanks	2/19/86	Takeoff	Fairbanks
	Start data	Point 1		Start data	Point 1
		North		Stop data	Tok
	Stop data	Tok			

TABLE 3. WAYPOINT POSITIONS

Name	Latitude	Longitude
North	N 67° 37' 00.00"	W 152° 50' 00.00"
Port Clarence	N 65° 14' 40.31"	W 166° 53' 12.55"
Tok	N 63° 19' 42.81"	W 142° 48' 31.90"
South	N 61° 30' 00.00"	W 155° 28' 00.00"
Point 1	N 65° 28' 00.00"	W 147° 05' 00.00"
Point 2	N 64° 07' 00.00"	W 148° 30' 00.00"
Point 3	N 64° 44' 00.00"	W 165° 00' 00.00"
Point 4	N 64° 57' 13.20"	W 156° 52' 40.04"

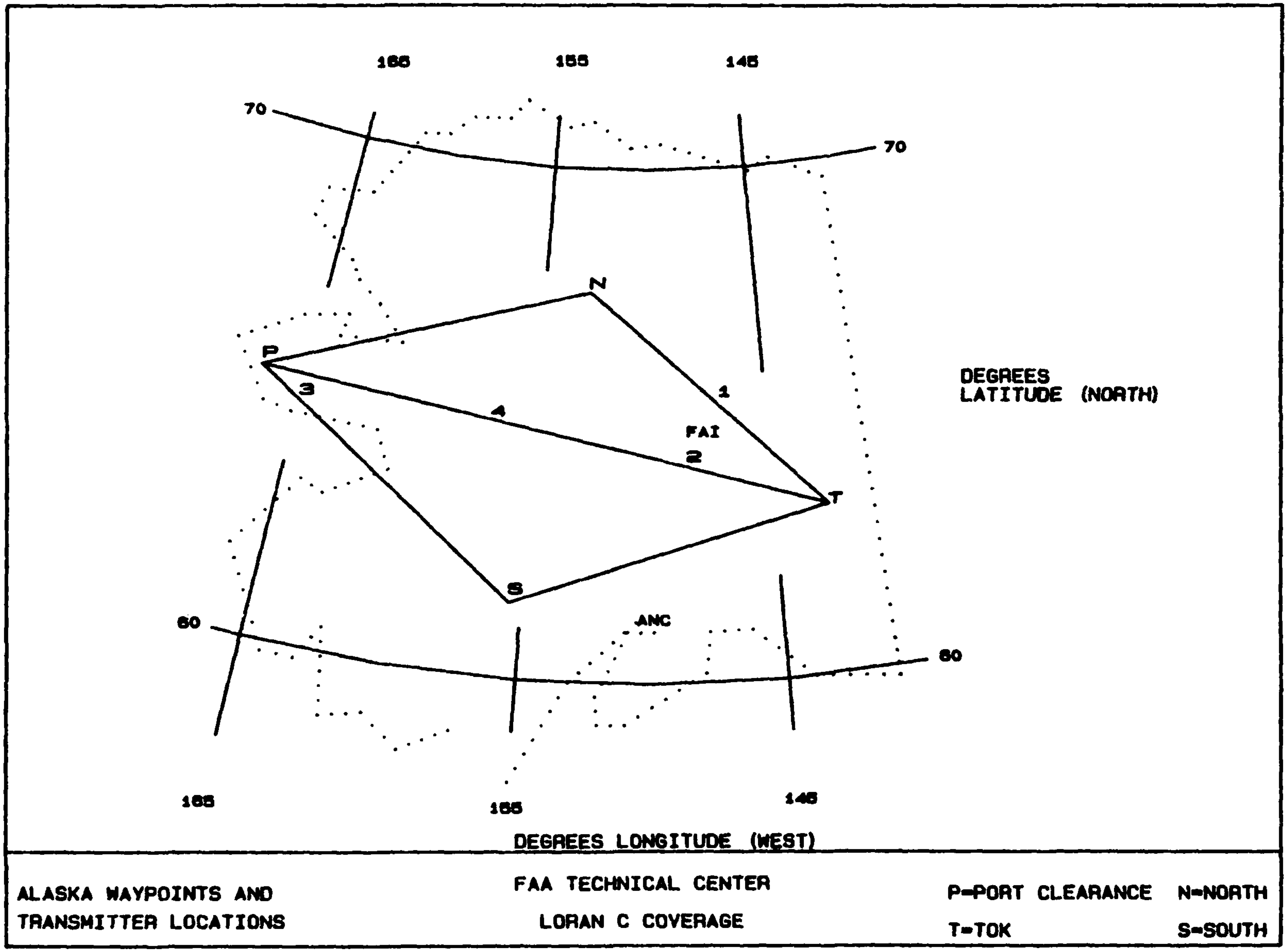


FIGURE 2. WAYPOINT AND TRANSMITTER LOCATIONS

The antenna calibration values for the ONI-7000 receivers were computed by subtracting the measured field strength from the calculated field strength (see appendix A). When near a Loran C transmitter, but in the far field, the attenuation does not vary significantly with different ground conductivities. Therefore, field strength can be calculated with reasonable accuracy by knowing the power radiated by the transmitter. Data used to calculate the radiated power appear in table 4.

TABLE 4. LORAN C TRANSMITTER CALIBRATION DATA

	Tok	Port Clarence
Radiation resistance	2.30 ohms	12.00 ohms
Electrical Pulse Analyzer		
Minimum	69.30 volts	37.70 volts
Maximum	70.60 volts	39.90 volts
Midpoint	70.00 volts	38.80 volts
Zero-peak antenna current	700.00 amps	388.00 amps
Peak power	563.50 kilowatts	903.26 kilowatts

CELL DATA.

A method was developed to compare data from summer and winter. Instantaneous samples were recorded each flight. A single measurement might not be typical of an area. Therefore, filtering or averaging of the data was necessary. It is impossible to compare data between seasons at exactly the same location because of normal flightpath variation.

It was decided to relate all data to specific locations along the proposed flight route. These specific locations were called cell centers. Cell centers were calculated at fixed distances along the flight route. All data within 5 nautical miles (nmi) of the cell center were included in the cell data. An average value for each type of data was obtained for each cell. Data from each cell was used for seasonal comparison.

Cell centers were constructed along the following great circle routes: Tok, Port Clarence, South, Tok, Port Clarence, North, and Tok. The latitude and longitude coordinates of these waypoints are listed in table 3. Figure 3 shows every 11 cell centers as asterisks on the map. The equations used to construct the cell centers are listed in appendix A.

The data base included in each cell center consisted of the following parameters: atmospheric noise, field strength, SNR derived from phase, SNR derived from field strength, and envelope-to-cycle difference (ECD). The field strength, SNR, and ECD values were obtained for the Tok, Port Clarence, and Narrow Cape Loran C stations. Time differences were not included as a parameter since the stations of interest were in different chains.

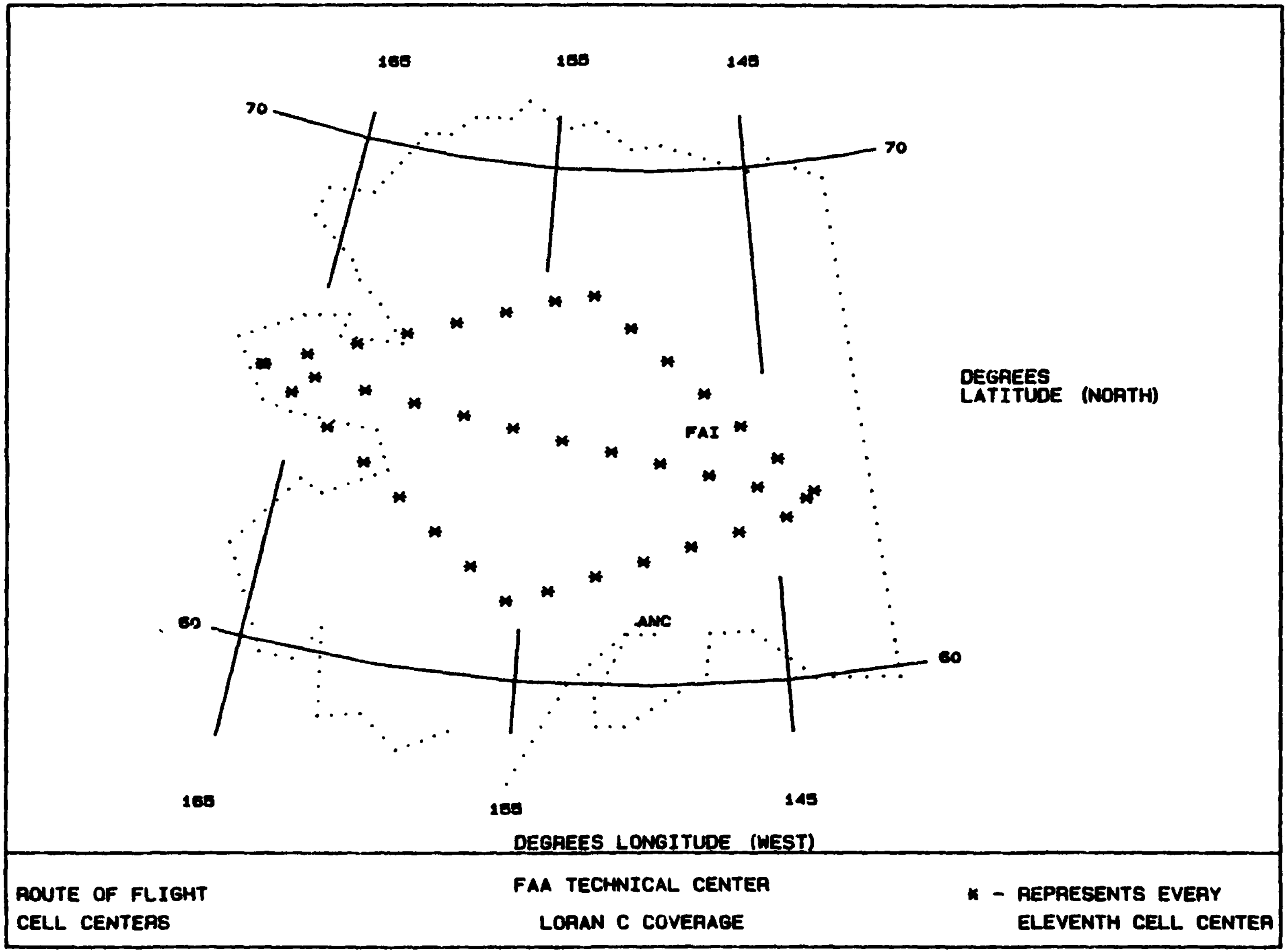


FIGURE 3. ALASKA CELL CENTERS

ANALYSIS OF RESULTS

ANTENNA CALIBRATION.

Figures 4 and 5 show plots of antenna calibration values in decibels per microvolt per meter (dB/μV/m) versus distance in nmi from the transmitter for ONI 7000 receivers 1 and 2, respectively. Each figure depicts an overlay of eight separate plots. Individual plots were obtained each time the receiver was within 100 nmi of the transmitters at Tok and Port Clarence during the summer and winter flights.

Analysis of the plots shows a tendency for the calibration value to increase when the receiver is further from the transmitter. This tendency is logical since free space signal propagation was assumed when predicting the calibrated field strength as a function of distance from the transmitter and not the actual propagation conditions found on the flightpath. Therefore, one would expect the predicted field strength to overestimate the actual field strength as distance between the transmitter and receiver increases, thus causing the antenna calibration value to increase as the distance to the transmitter increases. This results in an antenna calibration greater than actually exists as distance between transmitter and receiver increase.

An anomaly noted on both figures shows two flights whose values are higher than the rest. The high values happen to be from both summer and winter flights of the route from South to Tok. After examining a terrain map of that route, it was determined that approximately 40 miles from the transmitter the aircraft crossed a 10-nmi stretch of glacial ice stemming from Mount Kimball. The conductivity of glacial ice is much lower than the conductivity of other types of terrain, thereby resulting in reduced field strength in that area.

To verify that the higher calibration values were caused by the glacial ice, Millington's method (Related Documentation Nos. 2 and 3) was used to calculate field stength in the route from South to Tok, starting at 100 nmi from Tok. An assumption was made that most of the segment was flown over poor rocky soil (conductivity = 1 millimhos per meter (mmho/m)) except for a 10-nmi stretch of glacial ice (conductivity = 0.025 mmho/m) positioned 40 to 50 nmi from Tok. The resulting field strength did indeed show a decrease of about 6 dB in the glacial ice segment. This verifies the plots in figures 4 and 5 are correct.

The average antenna calibration values for ONI 7000 receivers 1 and 2 are listed in table 5. Data are grouped by receiver and separated by range to transmitter. Three separate groupings by range appear: 10 to 50, 50 to 100, and 10 to 100 nmi. The larger antenna calibration values for the 50 to 100-nmi range is due to increasing errors in calculated field strength. Calculated field strength did not include conductivity. The average antenna calibration value for receiver 1 was 2.0 and for receiver 2 was 5.7 dB. These values must be added to the measured field strength to obtain the true field strength.

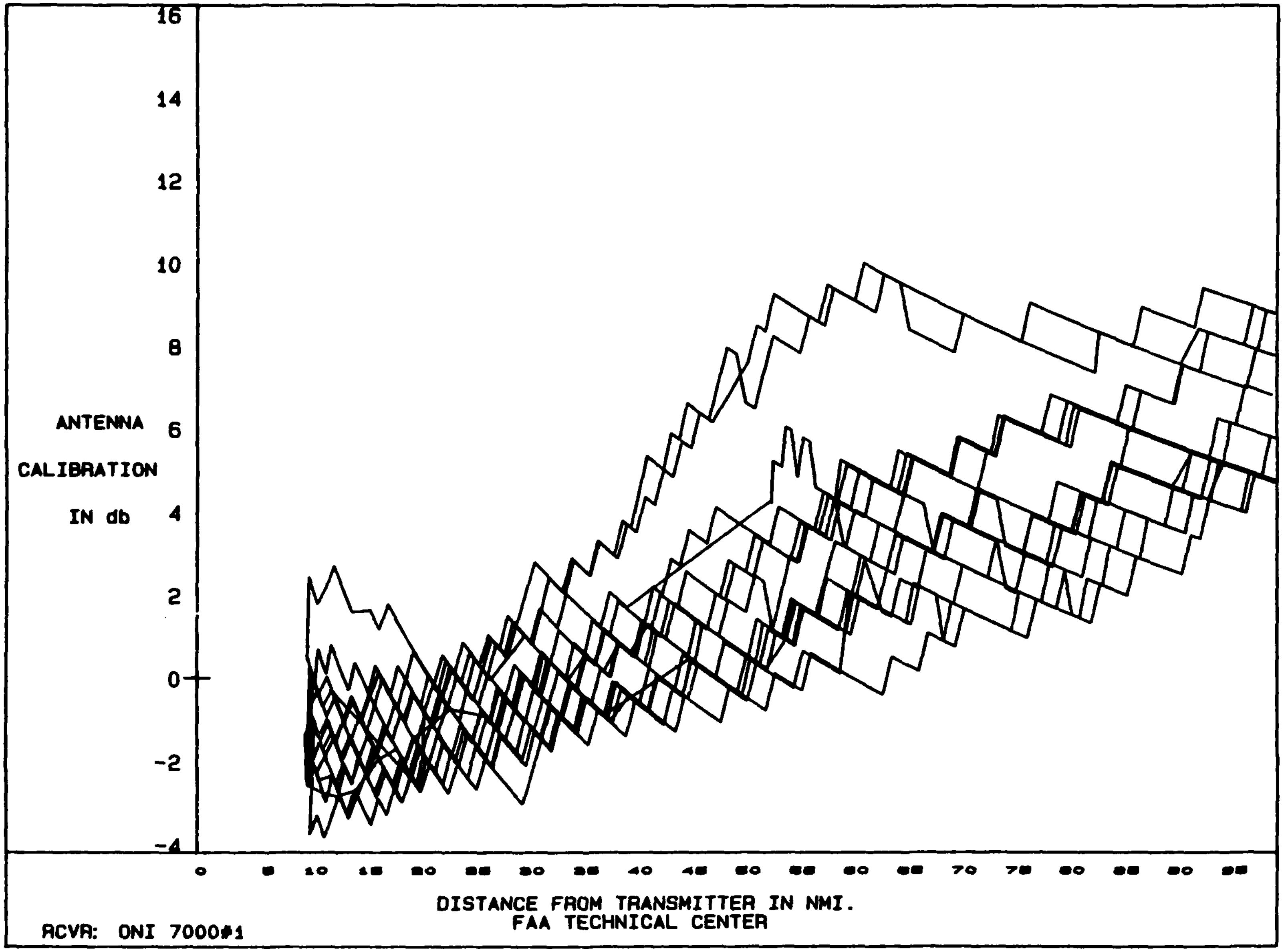


FIGURE 4. ANTENNA CALIBRATION VALUES FOR RECEIVER 1

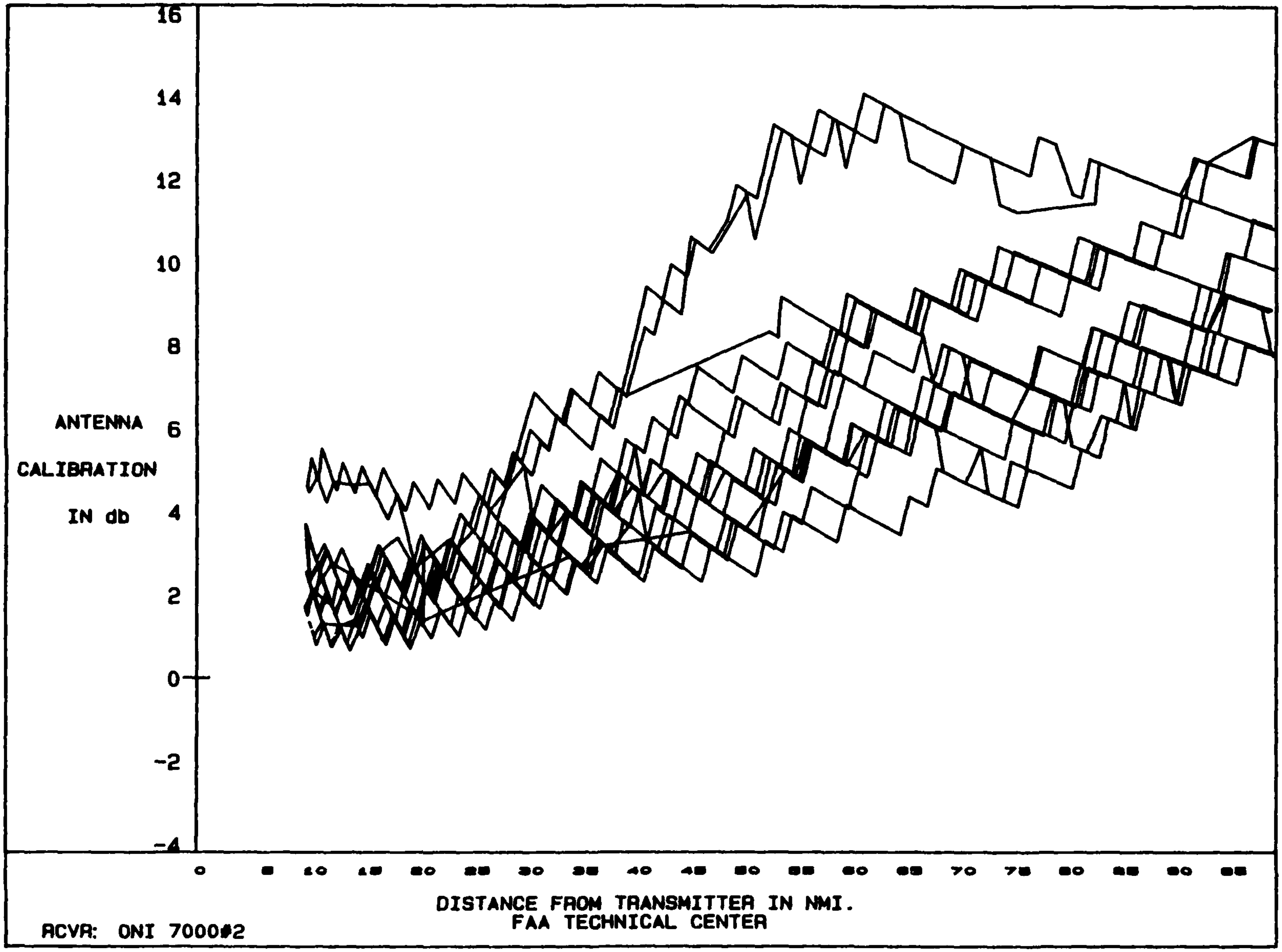


FIGURE 5. ANTENNA CALIBRATION VALUES FOR RECEIVER 2

TABLE 5. ANTENNA CALIBRATION VALUE RESULTS

	Receiver No. 1			Receiver No. 2		
	Mean	Min	Max	Mean	Min	Max
In Bound 10 - 50 nmi	2.6	0.8	4.2	6.1	4.1	8.0
In Bound 50 - 100 nmi	6.9	3.6	10.8	10.7	7.1	14.8
Out Bound 10 - 50 nmi	1.3	0.5	2.8	5.3	4.4	7.2
Out Bound 50 - 100 nmi	6.0	5.1	7.4	9.5	8.2	11.2
Total 10 - 50 nmi	2.0	0.5	4.2	5.7	4.1	8.0
Total 50 - 100 nmi	6.5	3.6	10.8	10.2	7.1	14.8

Note: Values above are in dB.

LORAN C PARAMETERS.

Loran C parameters include field strength, atmospheric noise, SNR derived from field strength, SNR derived from phase, and ECD. Loran C parameters were plotted for analysis.

The ONI 7000 Loran C receiver is a linear receiver. As a linear receiver it must maintain low distortion of the pulse shape. It is, therefore, important that the amplitudes of the pulses be equal to insure that analog to digital circuits or digitized samples have little error. A gain stage is used to maintain the signal amplitude constant. Field strength is obtained from the setting of the variable gain.

After reviewing all the field strength plots for both receivers, both seasons, and the three transmitters of interest, the field strength was found to be consistent for an area. Figures 6, 7, and 8 are typical plots of the field strength for Tok, Narrow Cape, and Port Clarence. These plots are of the winter season data from ONI 7000 Loran C receiver 1 of field strength in dB/μV/m. The asterisks represent portions of the flight where data are missing. In this case, the flight did not start at Tok but started at Point 4. (Note: in some cases asterisks indicate areas where the aircraft was off course, hence, there were no data within the cells.)

Values for field strength varied from 28 to 97 dB/μV/m for the three transmitters of interest with most values between 40 and 70. The field strength increased as the aircraft approached the station being measured. This is as expected, and the plots for field strength from Port Clarence, Tok, and Narrow Cape all coincided with this trend.

The difference between winter and summer field strength measurements at a point was minimal. The differences were usually only 1 or 2 dB. It was also noted that receiver 1's field strength measurement was generally higher than receiver 2. This is expected because the antenna calibration values were not applied to the data plotted.

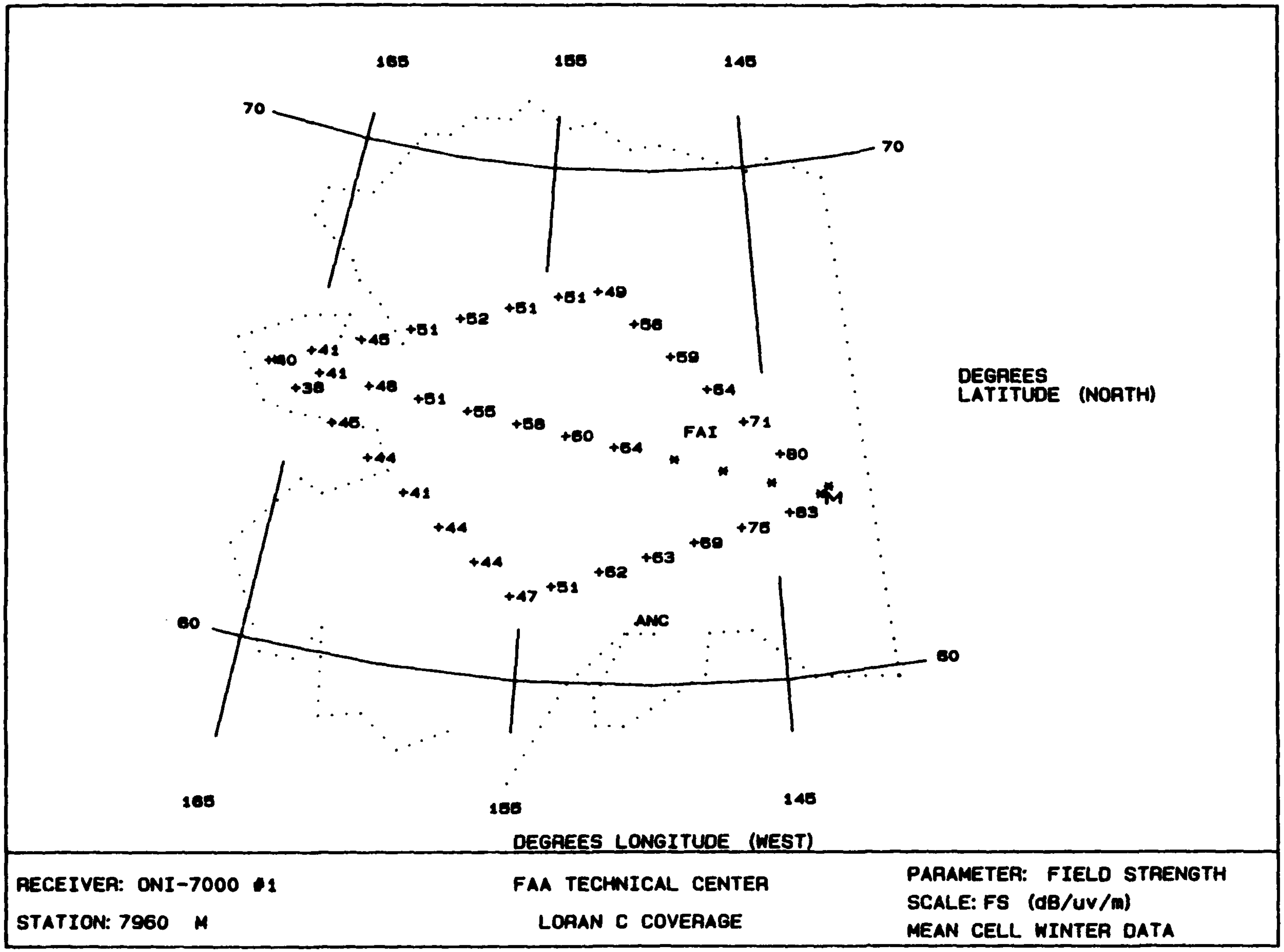


FIGURE 6. TYPICAL FIELD STRENGTH PLOT FOR TOK

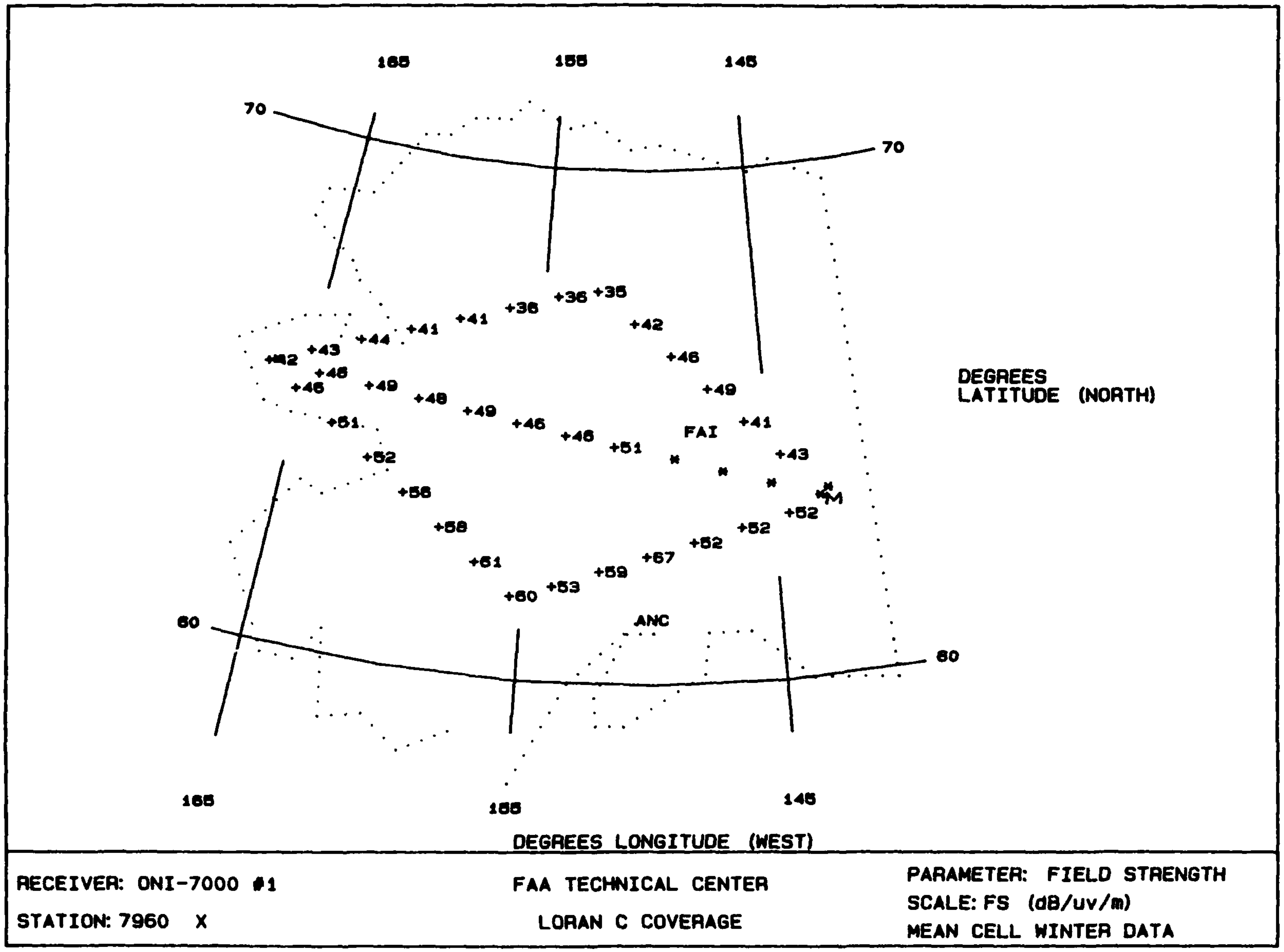


FIGURE 7. TYPICAL FIELD STRENGTH PLOT FOR NARROW CAPE

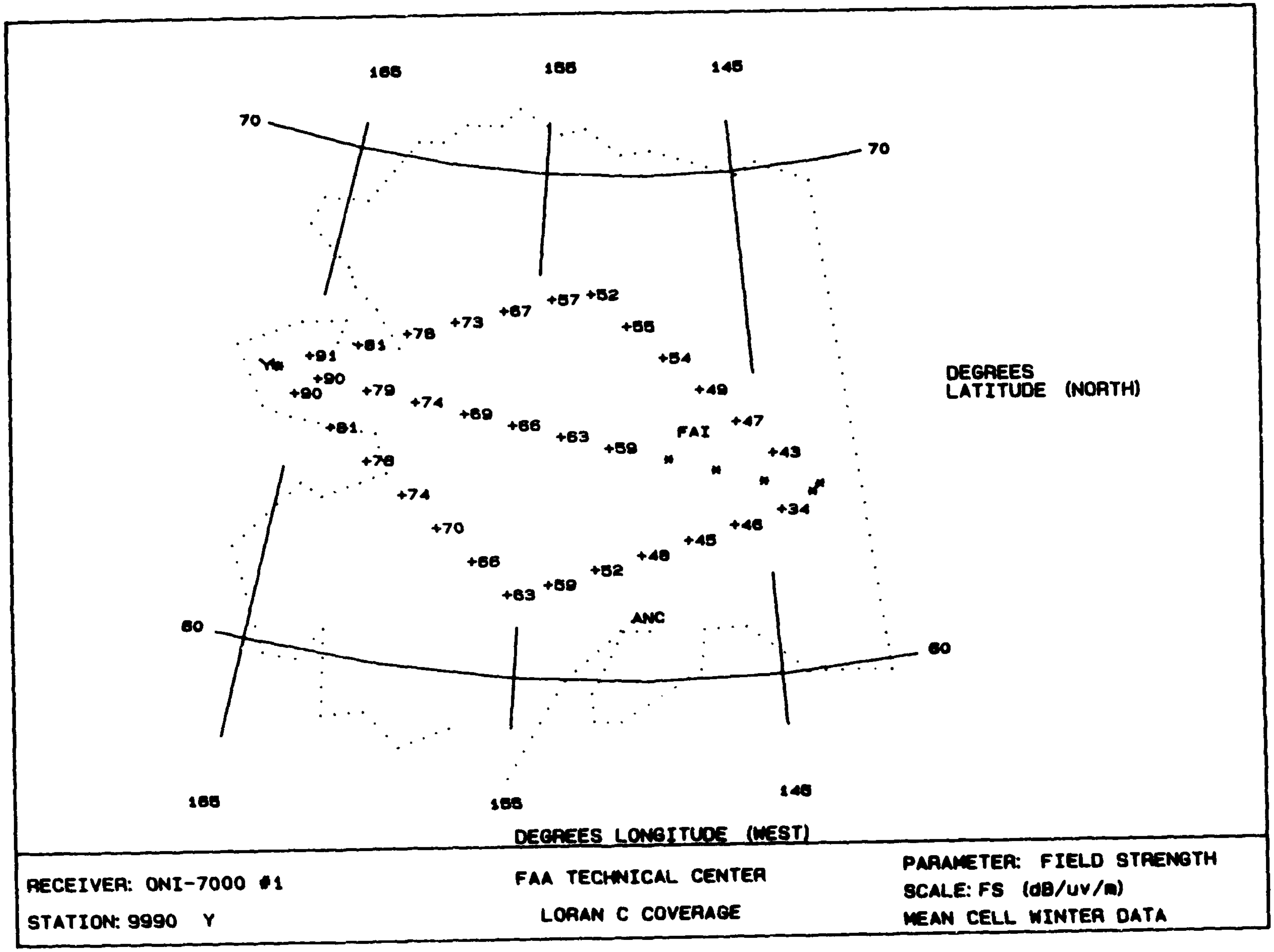


FIGURE 8. TYPICAL FIELD STRENGTH PLOT FOR PORT CLARENCE

The atmospheric noise is measured by randomly sampling the energy received at the front end of the receiver. When approaching a station the atmospheric noise increases because the noise measurement is contaminated with energy from the transmitter overflown. This energy does not interfere with reception of the signal from the transmitter overflown or other stations of the same chain. Operation near a transmitter will result in a false perception of increased noise level for all the stations in the same chain as the transmitter overflown.

However, the reception of the signal from the transmitter that is overflown will appear as cross rate interference to stations from other chains. Group repetition interval (GRI) rates are chosen to minimize the interference effect.

A plot of atmospheric noise is given in figure 9. The units are the same as those in figures 6 to 8. Most of the values for atmospheric noise were between 40 and 50 dB/μV/m with the total range between 40 and 63. The differences between summer and winter readings were usually 2 to 4 dB. Occasionally, in areas of charge buildup, such as flying through clouds, there was up to 15 dB difference.

Figures 10, 11, and 12 show plots of typical SNR by field strength (SNR(FS)) for Tok, Narrow Cape, and Port Clarence. Since the SNR(FS) is obtained by subtracting the atmospheric noise from the field strength, the SNR pattern should track the field strength. From figures 10, 11, and 12, one can see this is indeed true; when the field strength increases or decreases, the SNR(FS) does the same. As a station was approached, the SNR(FS) for that station increased. If atmospheric noise changed abruptly, the SNR(FS) did also.

SNR readings less than -10 dB are considered unreliable. The readings found to be less than that on the plots can be attributed to one of the following: proximity to a transmitter (measurement error because of atmospheric noise), flying through clouds, a rise in atmospheric noise, and distance from the transmitter to the receiver.

For SNR derived from phase (SNR(PH)), the measurement is either the standard deviation of the phase tracking point or the time constant required to keep that standard deviation constant. The Loran C signal is clipped or limited in the receiver before this measurement point. Because of this limiting, the SNR(PH) will tend to be higher than reported using field strength and atmospheric noise. SNR(PH) is plotted in figures 13, 14, and 15 for Tok, Narrow Cape, and Port Clarence.

ECD on the flight test receiver is primarily used to detect correct cycle acquisition. ECD plots are presented in appendix C. The data is in tenths of microseconds (μs). The plots indicate ECD decreases as distance increases from a transmitter; however, discontinuities are noted in the data. This can be attributed to a number of things. Skywave interference, perhaps off Mount McKinley, could cause a change in the ECD values. Overflight or proximity to a Loran C transmitter could affect the measurement. Various conductivities in the paths between the transmitter and the receiver also could affect the ECD measurements.

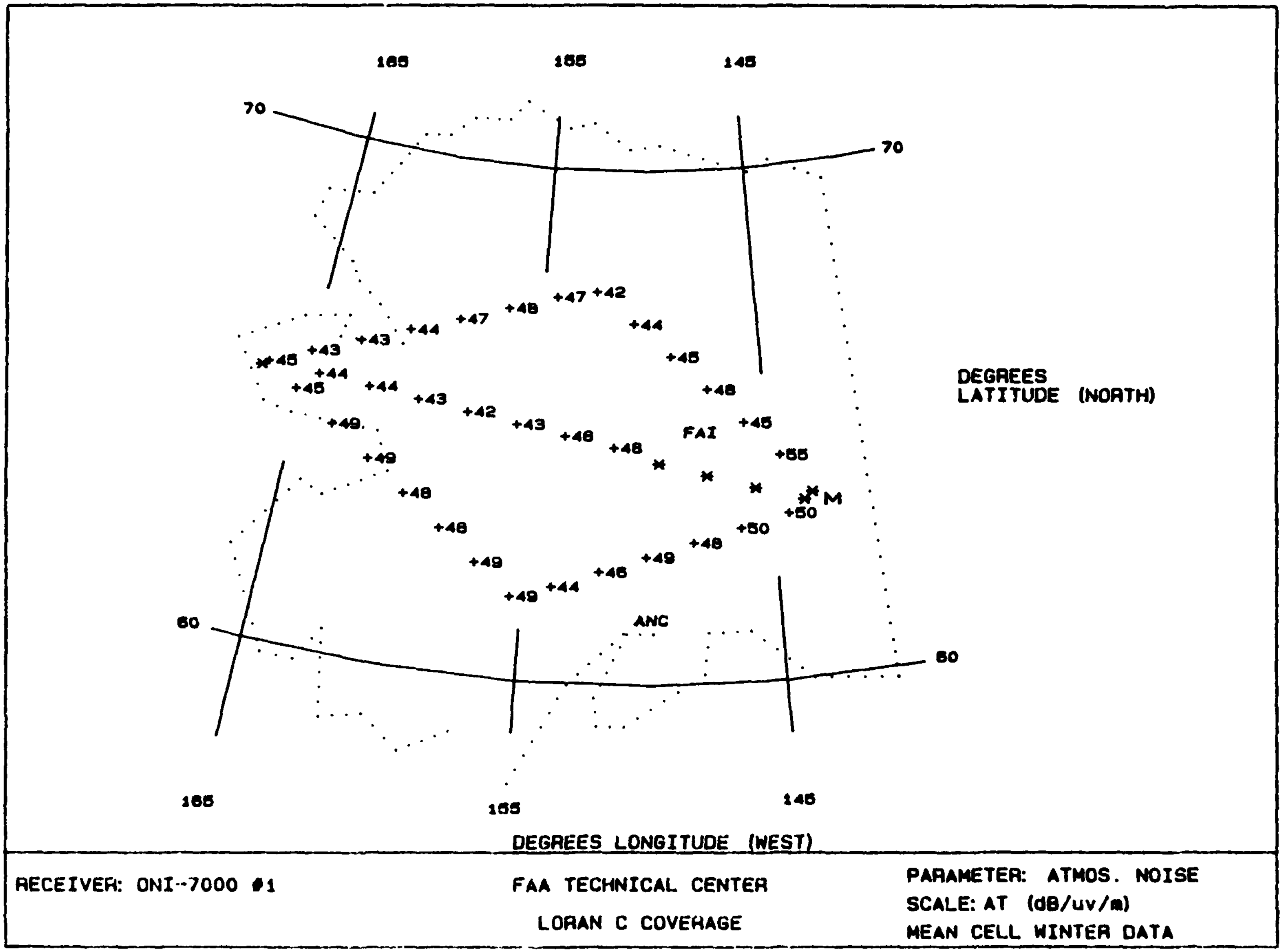


FIGURE 9. TYPICAL ATMOSPHERIC NOISE PLOT

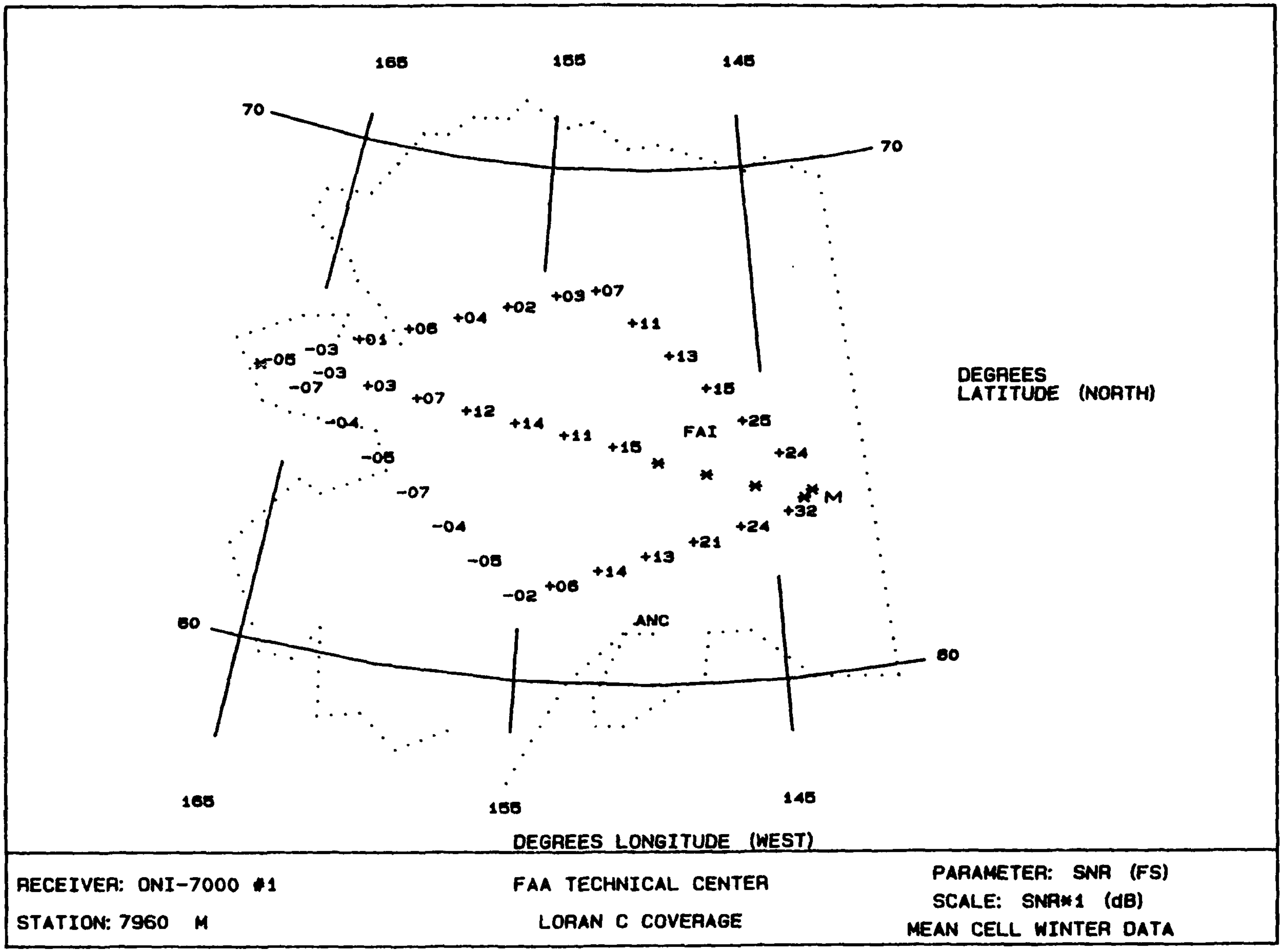


FIGURE 10. TYPICAL SNR(FS) PLOT FOR TOK

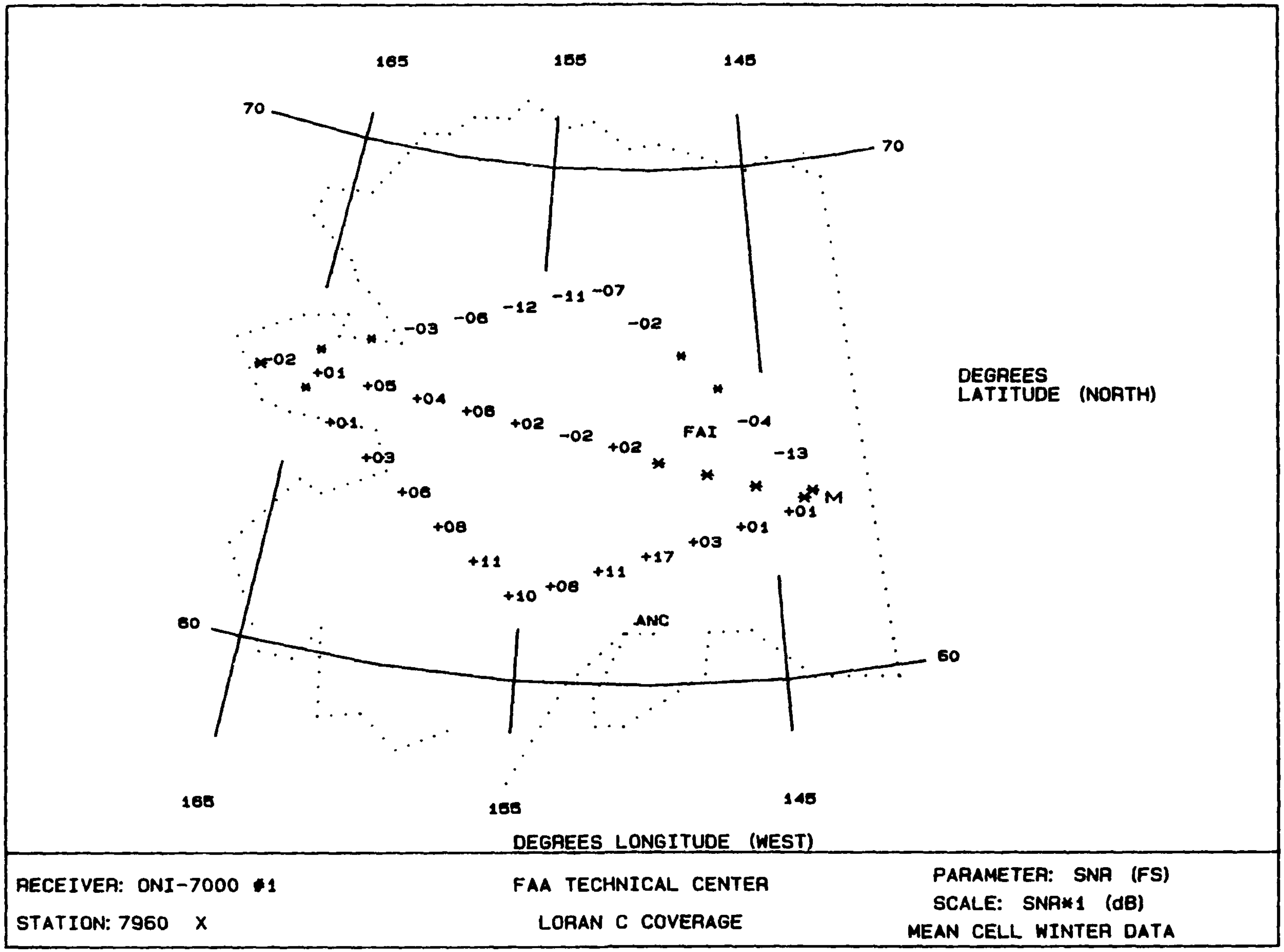


FIGURE 11. TYPICAL SNR(FS) PLOT FOR NARROW CAPE

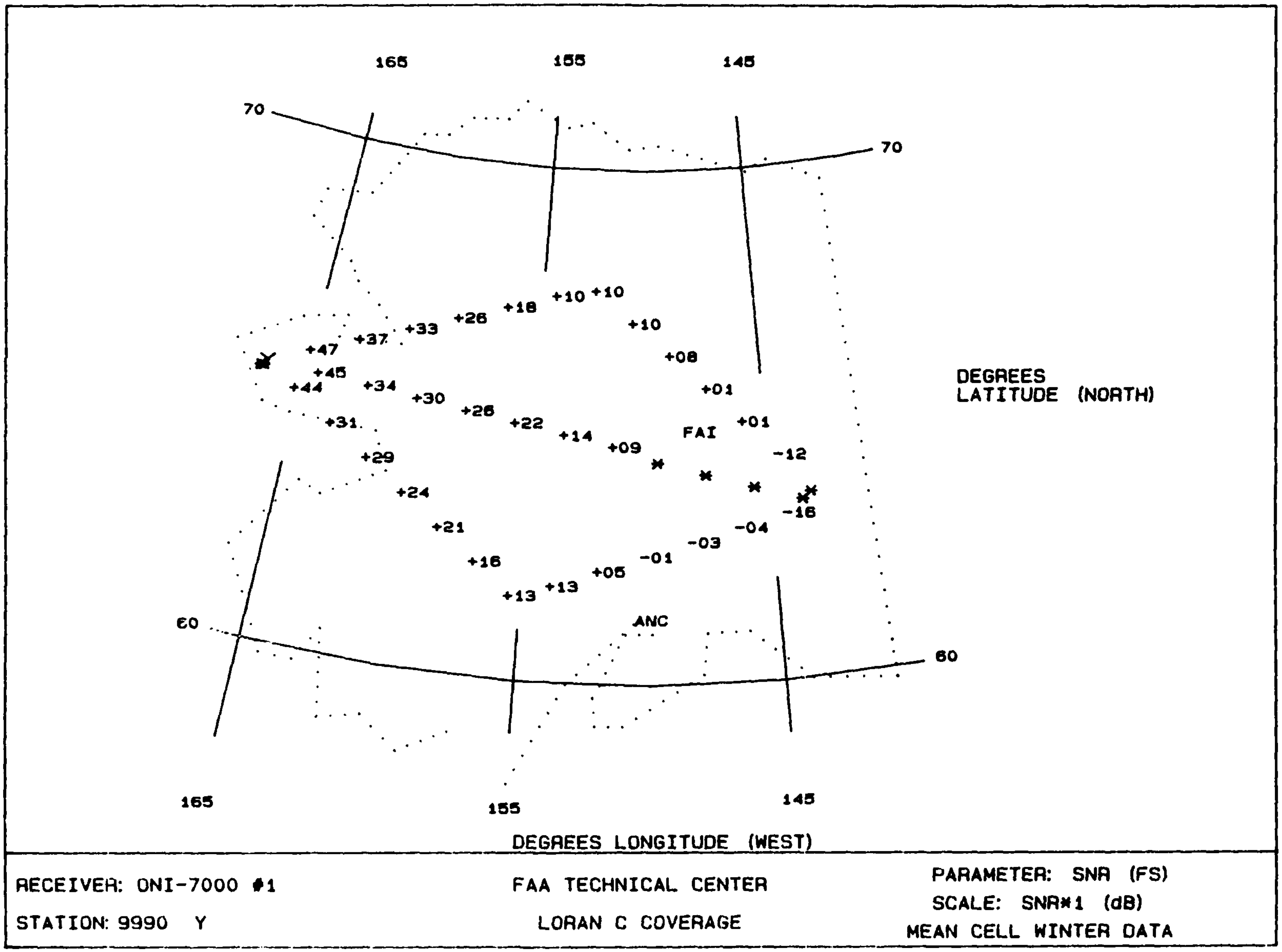


FIGURE 12. TYPICAL SNR(FS) PLOT FOR PORT CLARENCE

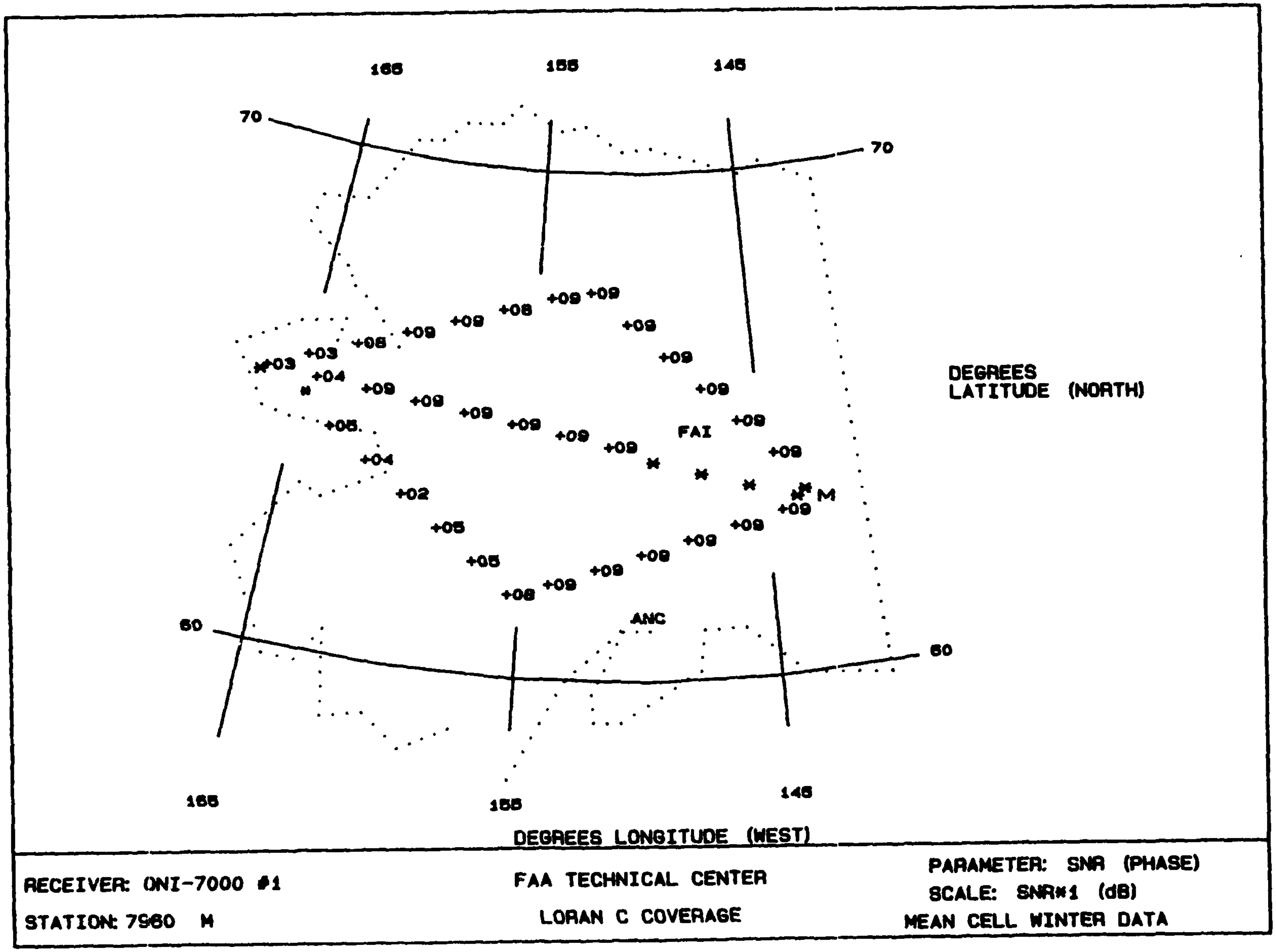


FIGURE 13. TYPICAL SNR(PH) PLOT FOR TOK

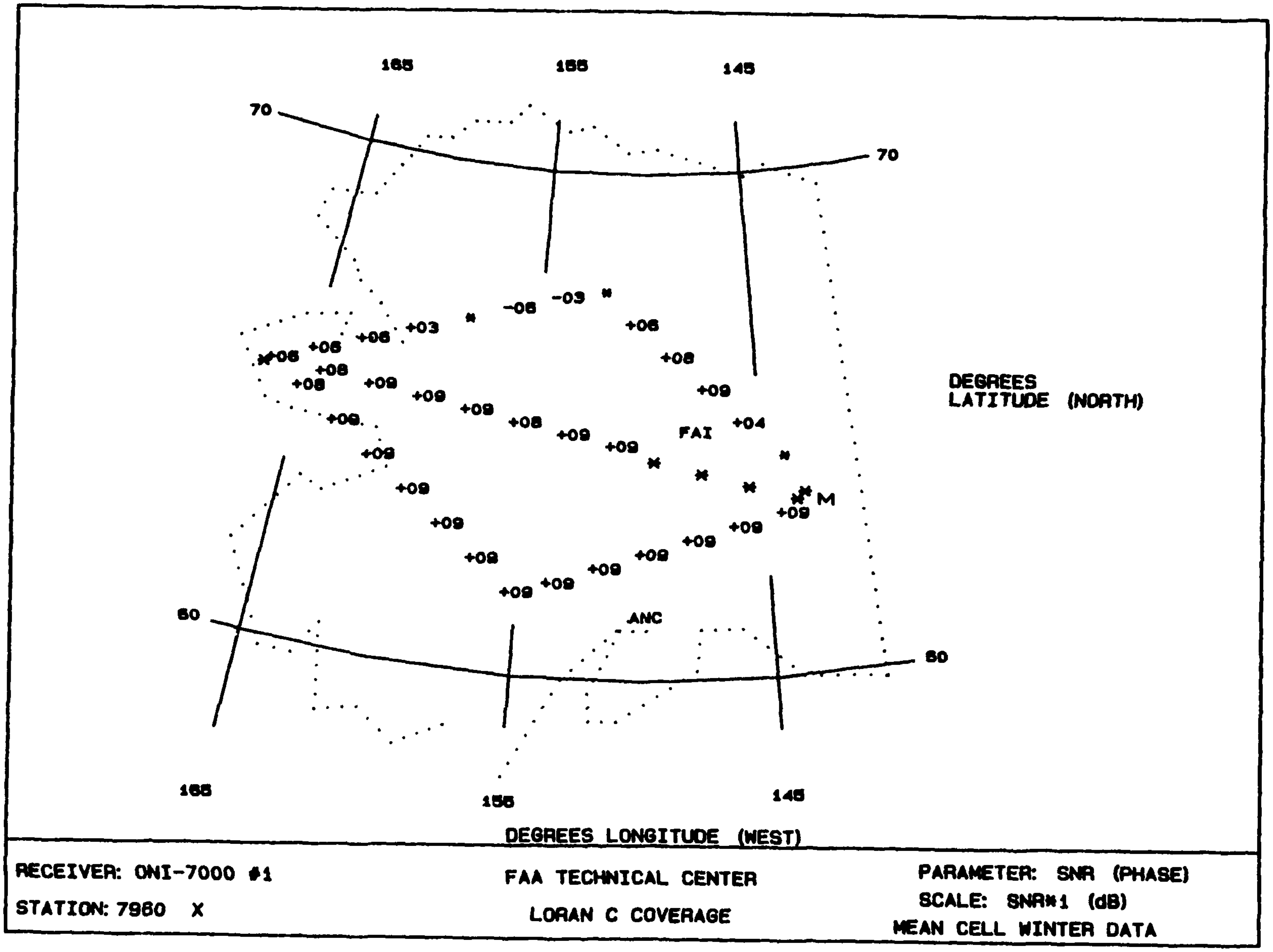


FIGURE 14. TYPICAL SNR(PH) PLOT FOR NARROW CAPE

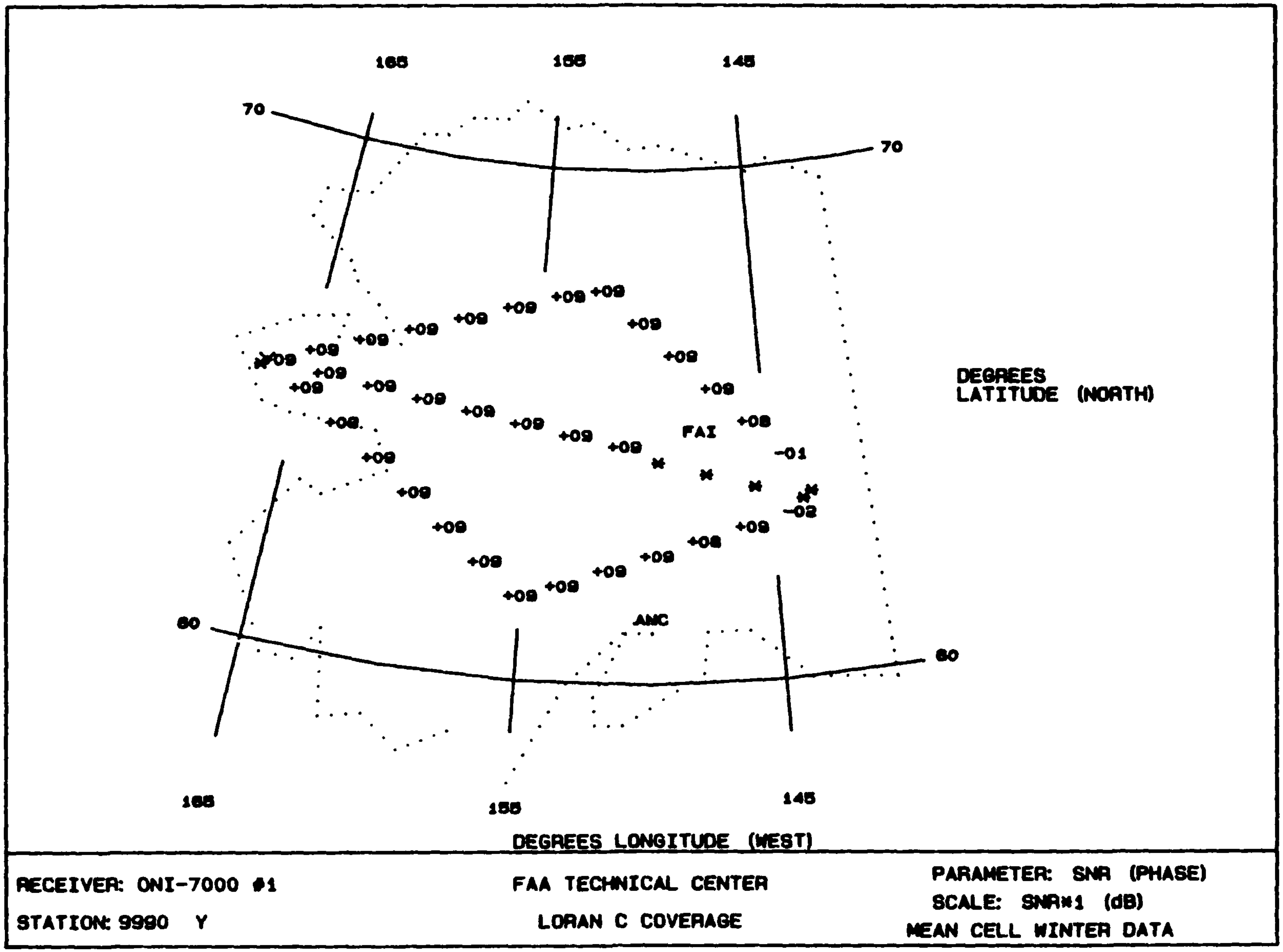


FIGURE 15. TYPICAL SNR(PH) PLOT FOR PORT CLARENCE

SPIRALS.

On two separate flights, descending spirals were flown to determine if the Loran C signal strength was affected by altitude. A spiral pattern was flown because it covers a particular area, so distance to station and conductivity wouldn't be concerning factors. Appendix B contains plots of the spiral data and a description of the parameters plotted. Note that on all the spiral data plots the cutoff for SNR (both phase and field strength) is +10.0 decibels (dB).

Looking at the sample spiral data plot in figure 16 shows that the field strength did not increase at higher altitudes as was predicted. Analyzing data from appendix B for the first descending spiral, from Point 2 to Fairbanks on September 10, 1985, indicates that the field strength from Tok increased as the aircraft descended, while field strength from Narrow Cape and Port Clarence remained fairly constant.

One explanation as to why Tok's field strength behaved differently was the fact that the location of the spiral was closest to Tok. The field strength should increase as the aircraft approaches a station. The distance from Tok to Point 2 is 160 nmi and from Tok to Fairbanks is 159 nmi. This is not significant enough to contribute to a 6 dB increase in field strength.

Upon examination of the data in the appendix for the second descending spiral, from Point 1 to Fairbanks on September 11, 1985, the field strength from plots for all three transmitters follows a similar trend. The trend seems to be a decrease in field strength around the only loop of the spiral, and then an increase in field strength as the aircraft continues descending in a straight path to Fairbanks. This coincides with plots of Tok from the first spiral, but not with Narrow Cape or Port Clarence.

Perhaps conductivity could contribute to the increase in field strength at the lower altitudes. To determine the effect of conductivity it is necessary to examine a map of Alaska (figure 17). The paths from Fairbanks to the three Loran C stations of interest are of concern. The signal path from Tok to Fairbanks is along the Tanana River for almost the entire distance, signals from Tok to Point 1 (north of Fairbanks) do not cross the Tanana River and signals from Tok to Point 2 (south of Fairbanks) cross the river only once for a short distance. The river, fresh water, has a conductivity of 5.0 mmho/m, whereas the rest of the path, probably poor rocky soil, has a conductivity of 1.0 mmho/m. This difference in conductivity from the start of the flightpath to the end of the flightpath could cause the 6 dB shift in field strength.

The signal paths from Narrow Cape to Point 1, Point 2, and Fairbanks are essentially identical, crossing both seawater, freshwater, and land. The data from the first spiral flight appear reasonable. The dip and then increase of field strength for the second spiral flight is inconsistent with the results obtained from the first spiral flight.

Signals from Port Clarence to Point 1, Point 2, and Fairbanks tranverse approximately the same terrain. The only prominate terrain features near the signal path are Norton Bay, the Yukon River, the Tanana River, and the Kaiyuh Mountains. As the aircraft comes closer to Fairbanks, the signal path goes over more of the Yukon and Tanana rivers. This terrain should cause the field strength to increase. This does not explain why the field strength during the flightpath for the spiral from Point 2 remained fairly constant but varied during the spiral flight from Point 1.

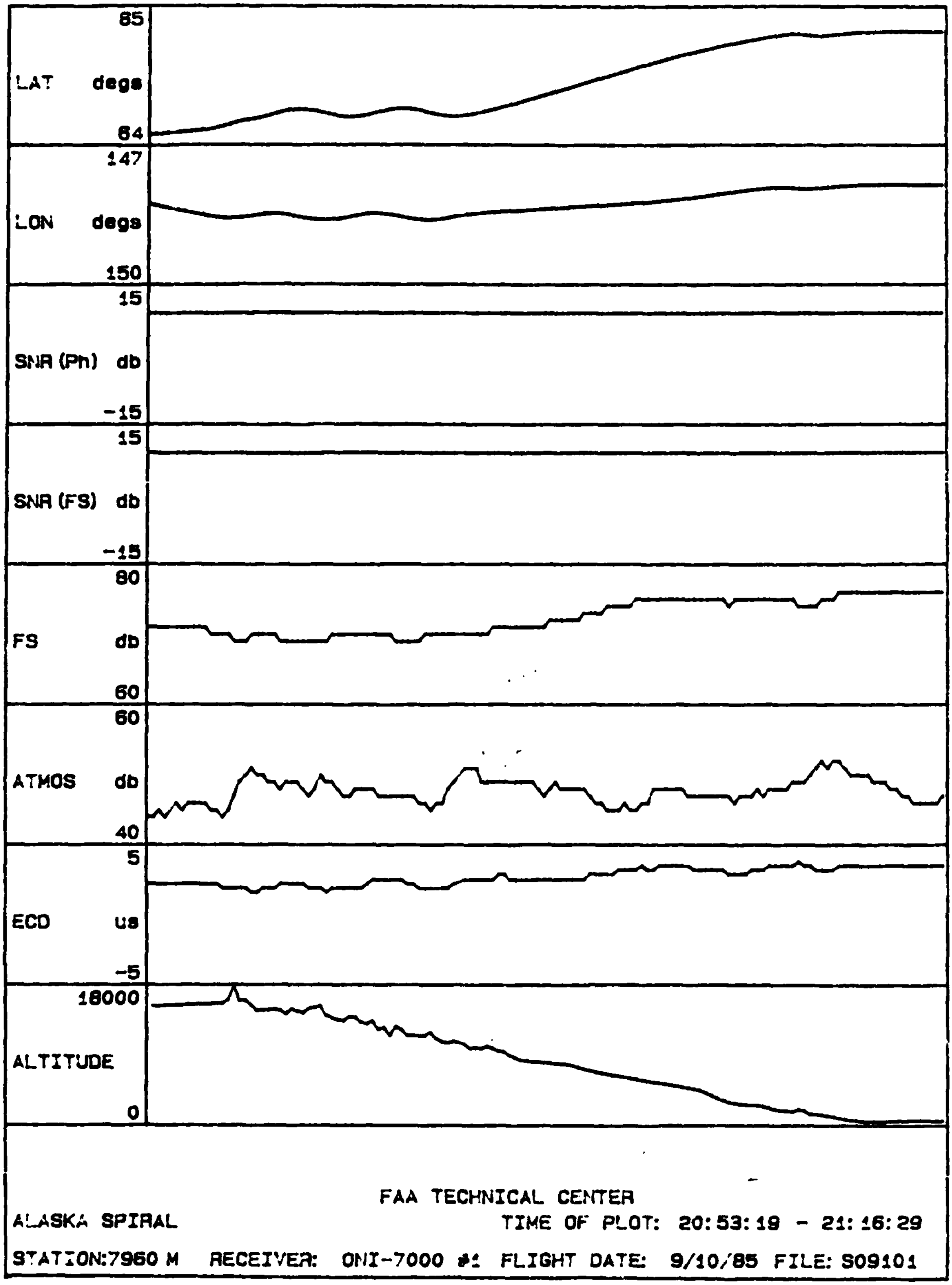


FIGURE 16. SAMPLE SPIRAL DATA PLOT

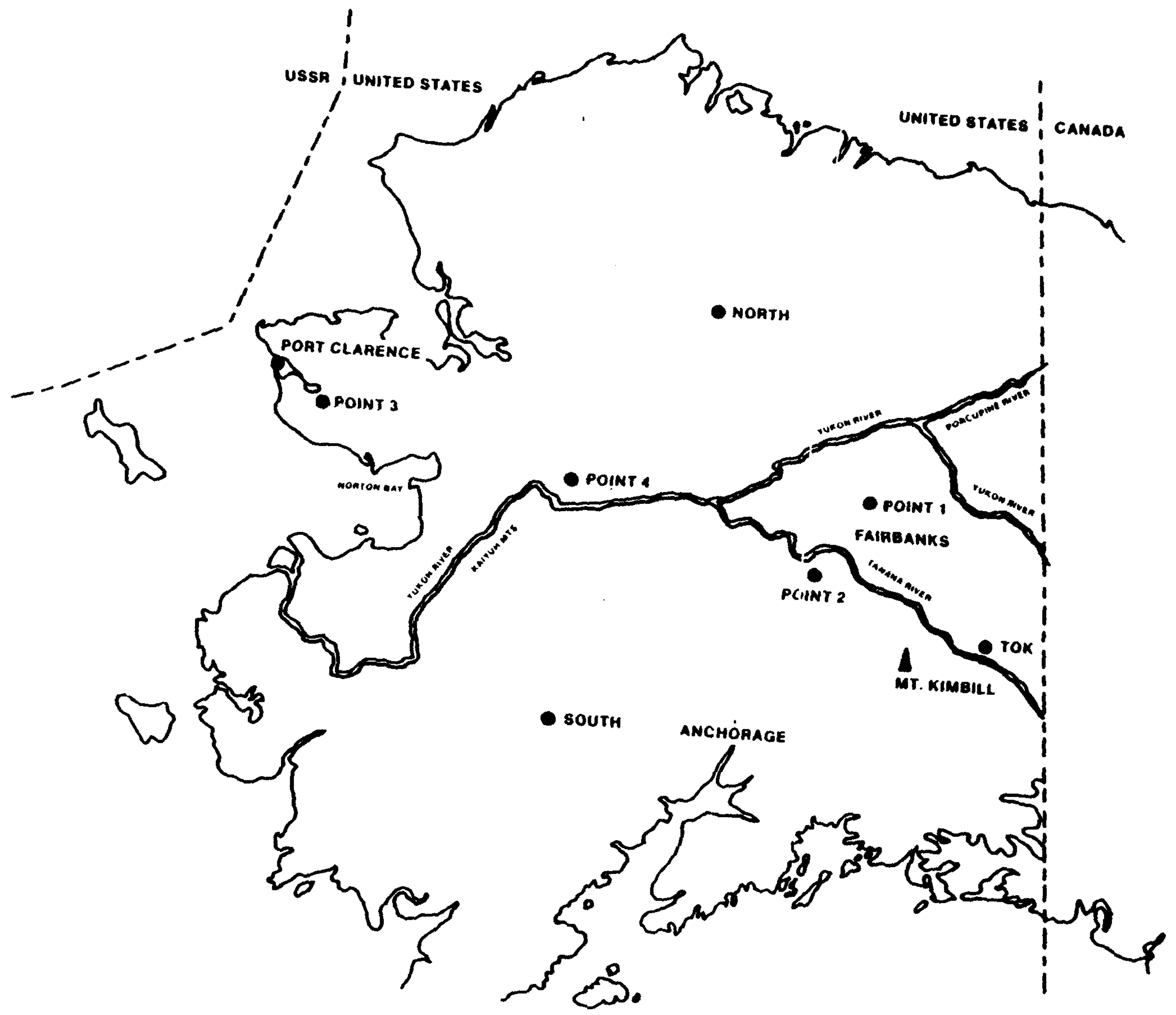


FIGURE 17. MAP OF ALASKA

On most of the plots the field strength appears to drop to its lowest point during the actual spiral and then increase during the last straight course segment of the flight, all during descent. The altitude loss during the first spiral flight, which contained two complete loops, was about 7000 feet. The loss during the only loop of the second spiral flight was about 9000 feet. The spirals on both flights started at an altitude of about 17000 feet. The loss of altitude after the spirals was between 8000 and 10000 feet. The increase in field strength for the last segment of the flight is more than the drop of field strength during the spiral. Altitude doesn't seem to be a factor. Perhaps acceleration caused by the spiral turns affects the receiver operation.

The ECD values tend to increase slightly toward the end of the flight, similar to the trend observed in the field strength measurements.

The field strength measurements tend to be higher near the ground or show no change with altitude variation. Hence, the relationship of signal strength with respect to altitude was indeterminate.

CONCLUSIONS

Measured field strength from Tok, Narrow Cape, and Port Clarence was generally above 40 decibels per microvolt per meter (dB/μV/m) during both winter and summer flights in Alaska. The field strength from a transmitter increased as the aircraft approached that transmitter. Both field strength and atmospheric noise showed consistency between seasons, with the difference being minimal (1 - 2 dB for field strength and 2 - 4 dB for atmospheric noise). As a result of the minor variation in field strength and noise for different seasons, the signal-to-noise ratio (SNR) remained constant between seasons. The occasions when the SNR values were less than -10 dB were accounted for by weather, proximity to a transmitter, or conductivity path from the transmitter to the receiver.

The relationship of signal strength with respect to altitude during the spiral turns was indeterminate. The field strength tended to be higher near the ground or show no change with altitude variation.

Flight measurements indicate adequate signal strength exists from the three Loran C stations over the routes flown to justify dual rating Port Clarence. Port Clarence can then function as a new secondary in the Gulf of Alaska Loran C chain (7960) in addition to its current function as the Yankee secondary in the North Pacific Loran C chain (9990).

RECOMMENDATIONS

It is recommended to dual rate Port Clarence on the Gulf of Alaska chain. This will provide the proper chain structure to increase the area in the interior of Alaska where Loran C navigation is possible.

APPENDIX A

EQUATIONS

CALCULATION OF FIELD STRENGTH.

The equation for field strength is:

$$FS = 20*\log(SF*FS1)$$

where:

FS = RMS field strength 25 microseconds into the transmitted pulse in decibels above 1 microvolt/meter

SF = scale factor to convert field strength at peak of pulse to 25 microseconds into the pulse = 0.506

FS1 = zero-peak field strength at maximum RF cycle as a function of distance from transmitter and radiated power

$$FS1 = \frac{\text{298000 microvolts/meter}}{\text{range in kilometers}} * \text{square root of } P$$

$$P = \text{the peak radiated power} = \frac{R * i * i}{2 * 1000}$$

range in kilometers = range in nautical miles * 1.852

R = radiation resistance of antenna in ohms

i = zero-peak antenna base current at maximum RF cycle in amps

Note: The above equations are only valid for a range of 10 to 100 nmi from the transmitter.

CONSTRUCTION OF CELL CENTERS.

To calculate the locations of cell centers between two waypoints the initial distance and true course of the great circle route from the start waypoint must first be computed. This distance and true course are used to calculate the next cell center location. Each intermediate cell center location is calculated using the distance and true course from the previous cell center location to the end waypoint.

The following three equations are used to compute the initial distance and true course of the great circle route from the start waypoint to the stop waypoint.

$$gcd = 60*\arccos(\sin(las)*\sin(lad) + \cos(las)*\cos(lad)*\cos(lod-los))$$

$$tcs = \arccos\left[\frac{\sin(lad) - \sin(las)*\cos(gcd/60)}{\sin(gcd/60)*\cos(las)}\right]$$

if sin(lod - los) < 0 then tcs = 360 - tcs

To determine the longitude of an intermediate cell:

$$dlo = \frac{\sin(tcp)*nmi}{60*\cos(lap)}$$

loi = lop + dlo

if loi > 180 then loi = -360 + loi

if loi < -180 then loi = 360 + loi

To determine the latitude of an intermediate cell:

$$lai = \arctan\left[\frac{\tan(lad)*\sin(loi - los) - \tan(las)*\sin(loi - lod)}{\sin(lod - los)}\right]$$

To determine distance and true course from this intermediate cell to end waypoint:

$$gci = 60*\arccos(\sin(lai)*\sin(lad) + \cos(lai)*\cos(lad)*\cos(lod-loi))$$

$$tci = \arccos\left[\frac{\sin(lad) - \sin(lai)*\cos(gci/60)}{\sin(gci/60)*\cos(lai)}\right]$$

if sin(lod - loi) < 0 then tci = 360 - tci

where:

1. All angles are in degrees

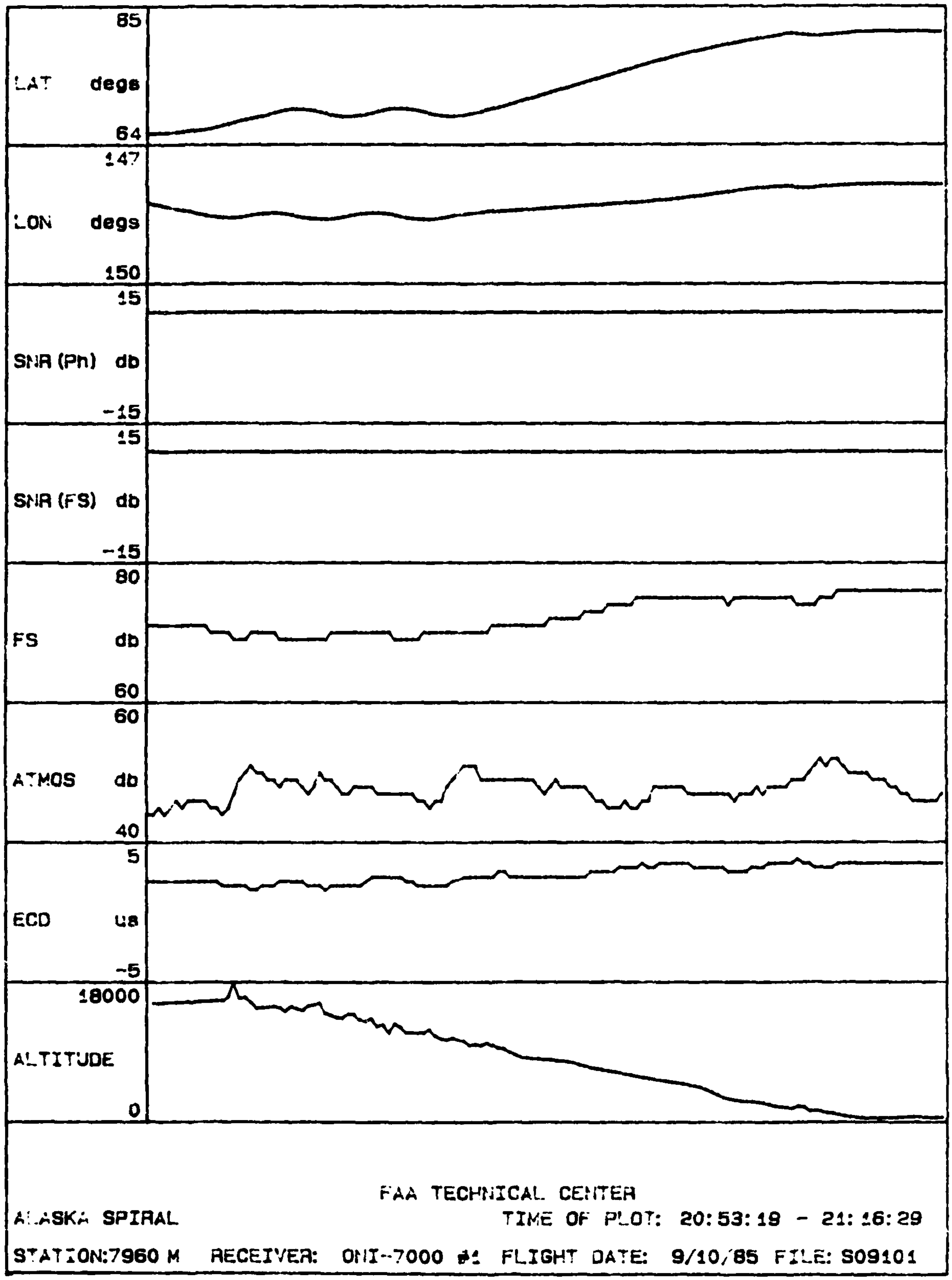
2. North latitudes and east longitudes are positive.

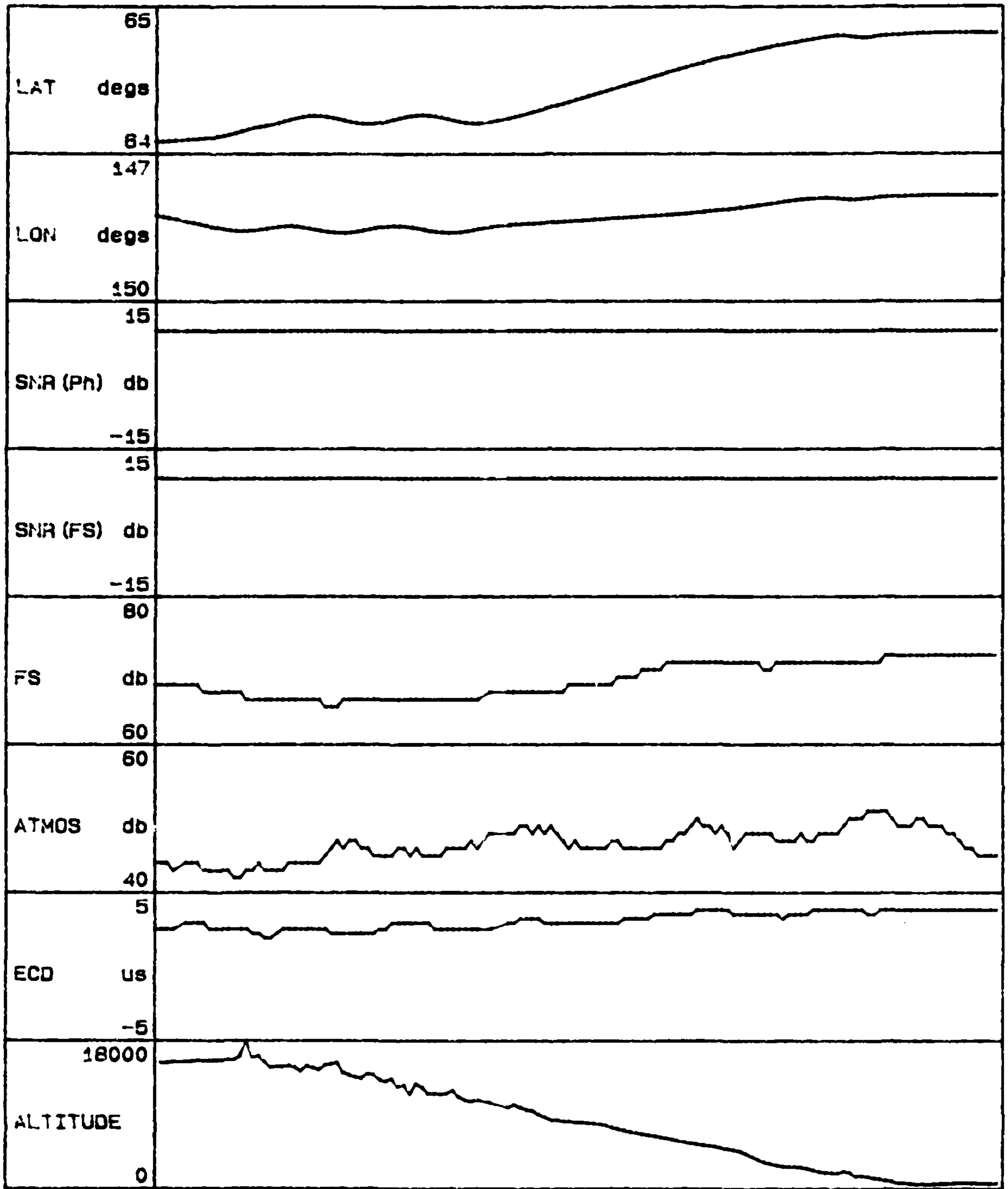
3. gcd = great circle distance from start to destination waypoint
   las = latitude of start waypoint
   lad = latitude of destination waypoint
   lod = longitude of destination waypoint
   los = longitude of start waypoint
   tcs = initial true course for great circle route
   dlo = shift in longitude between present and new cell center
   tcp = true course for previous cell center
   nmi = distance between cell centers in nautical miles = 5 nmi
   lap = latitude of previous cell center
   loi = longitude of present cell center
   lop = longitude of previous cell center
   lai = latitude of present cell center
   gci = great circle distance from an intermediate point to destination
   tci = initial true course for present cell center

APPENDIX B

SPIRAL DATA PLOTS

The plots in this appendix show the data collected during the spiral turns made near Fairbanks on September 9 and 10, 1985. The plot is divided into eight sections with vertical axes including: latitude (LAT) and longitude (LON) in degrees (degs); signal-to-noise ratio (SNR) derived from phase (Ph) and field strength (FS) in decibels (dB); field strength and atmospheric noise (ATMOS) in decibels per microvolt per meter; envelope-to-cycle difference (ECD) in microseconds (μs); and altitude in feet. The horizontal axis of each section is the time axis. The times for each plot is given at the bottom of the plot along with the date, file name, receiver number, and chain and station involved.

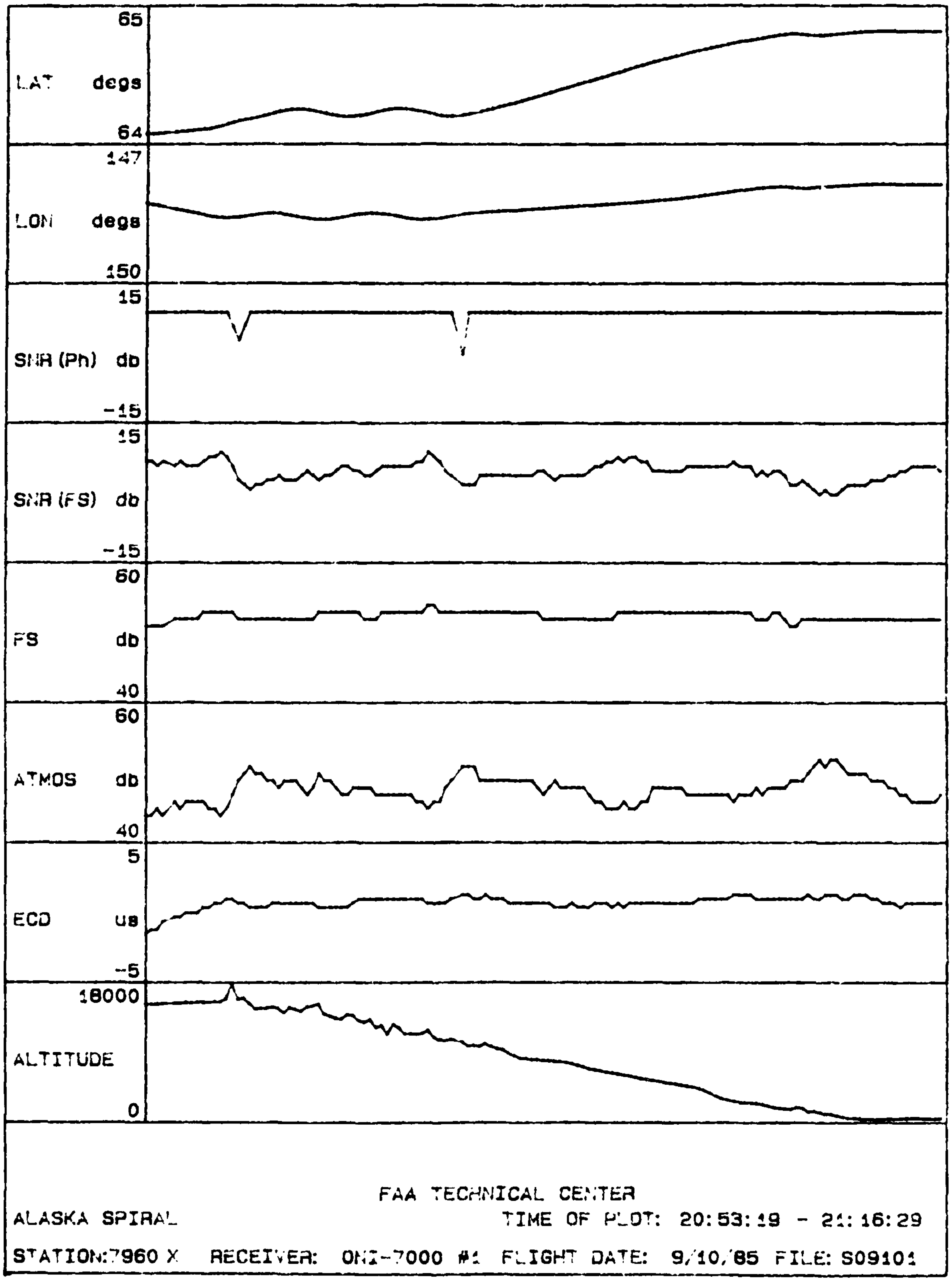

85
LAT degs
64
147
LON degs
150
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
80
FS db
60
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 20:53:18 - 21:16:29
STATION:7960 M RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/10/85 FILE: S09101

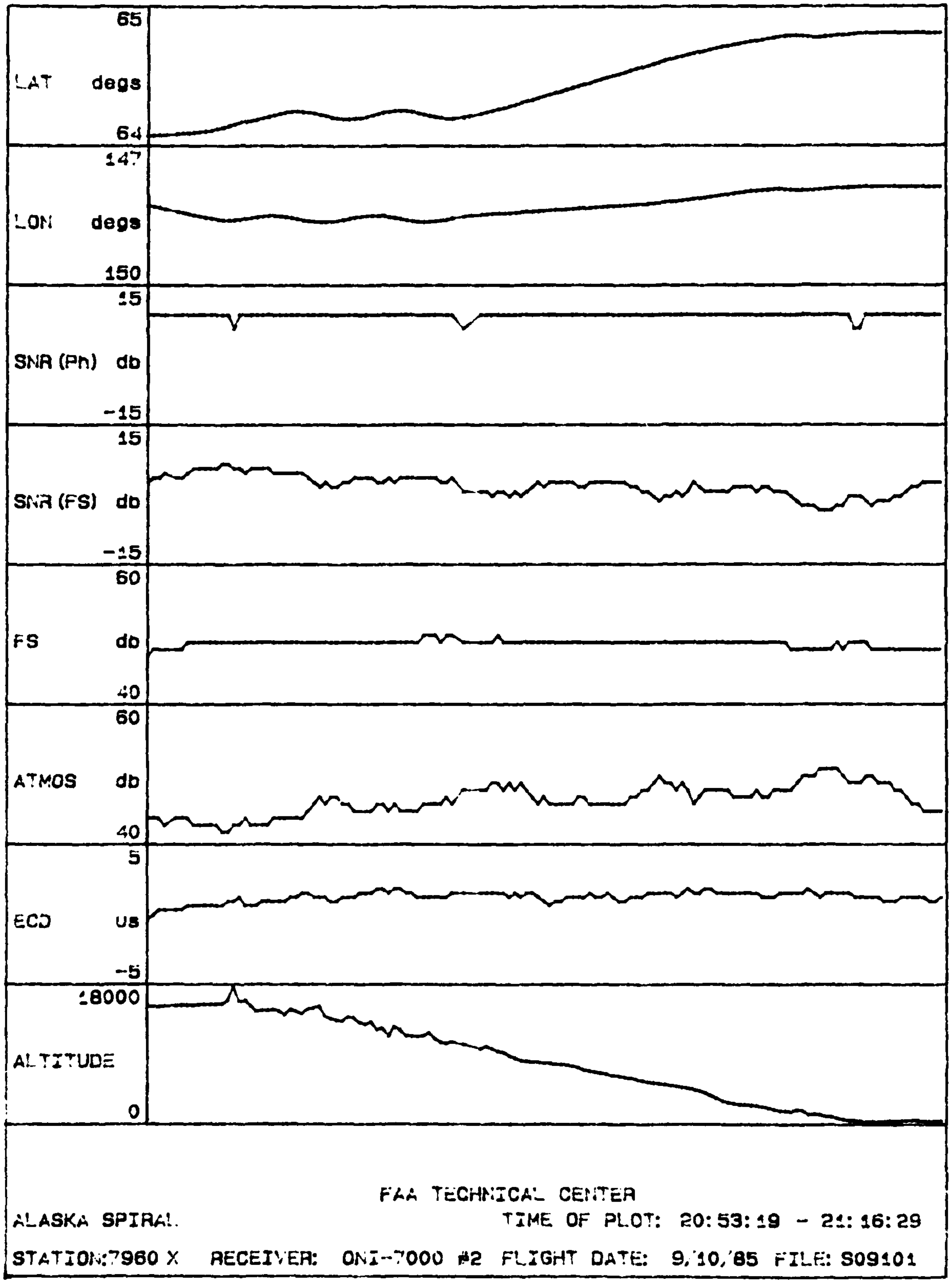


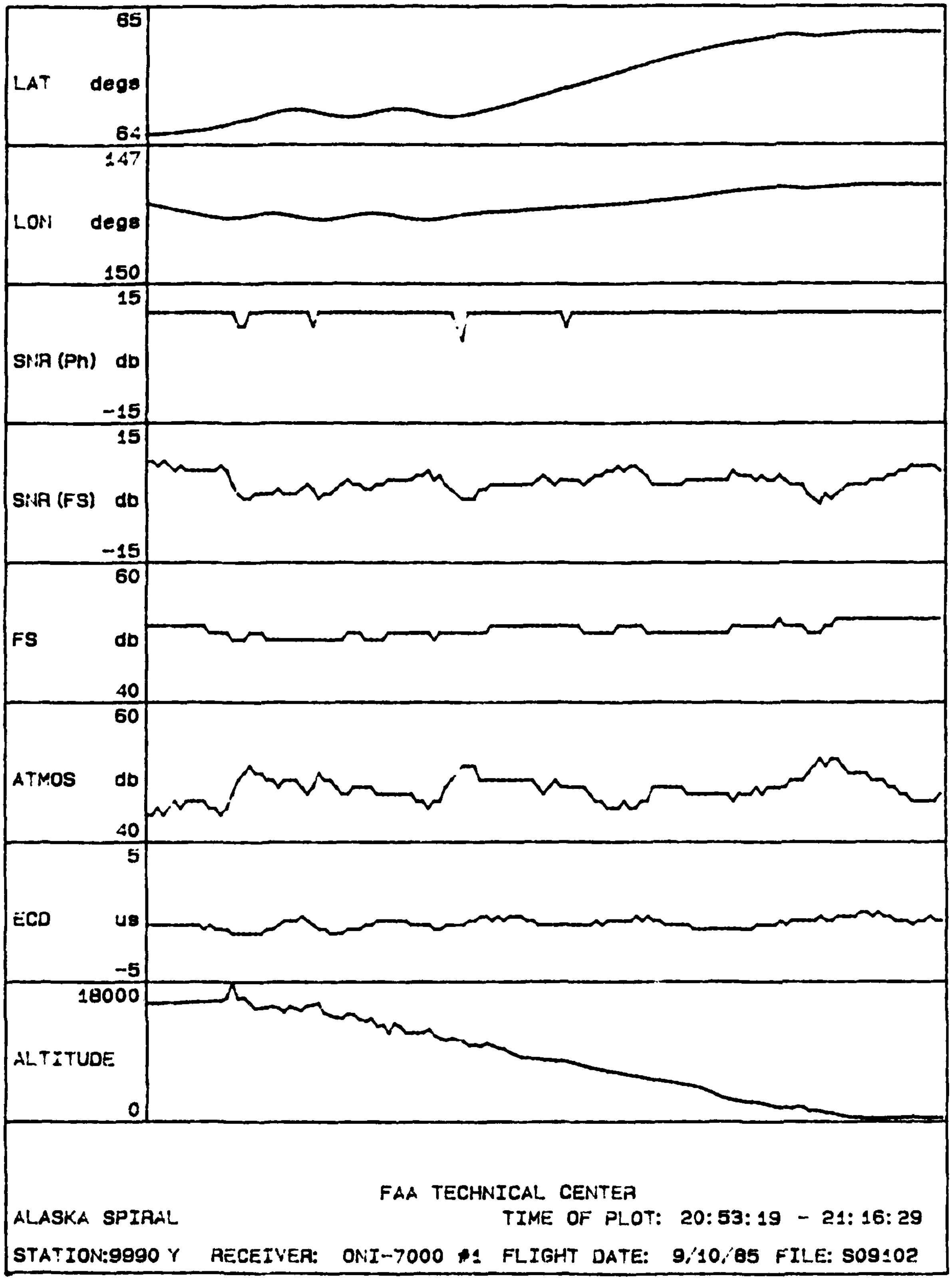
FAA TECHNICAL CENTER

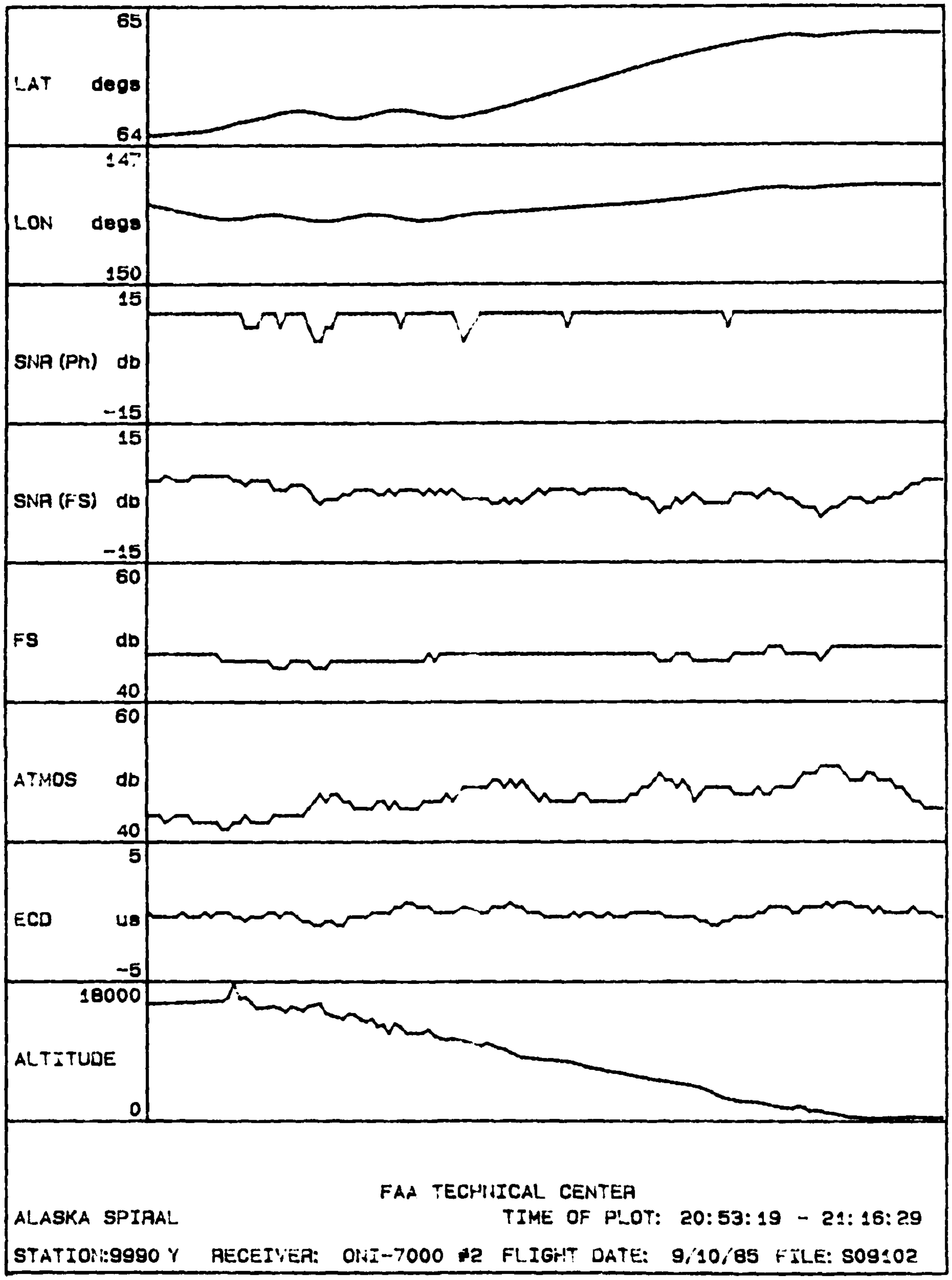
ALASKA SPIRAL TIME OF PLOT: 20:53:19 - 21:16:29

STATION:7960 M RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/10/85 FILE: S09101

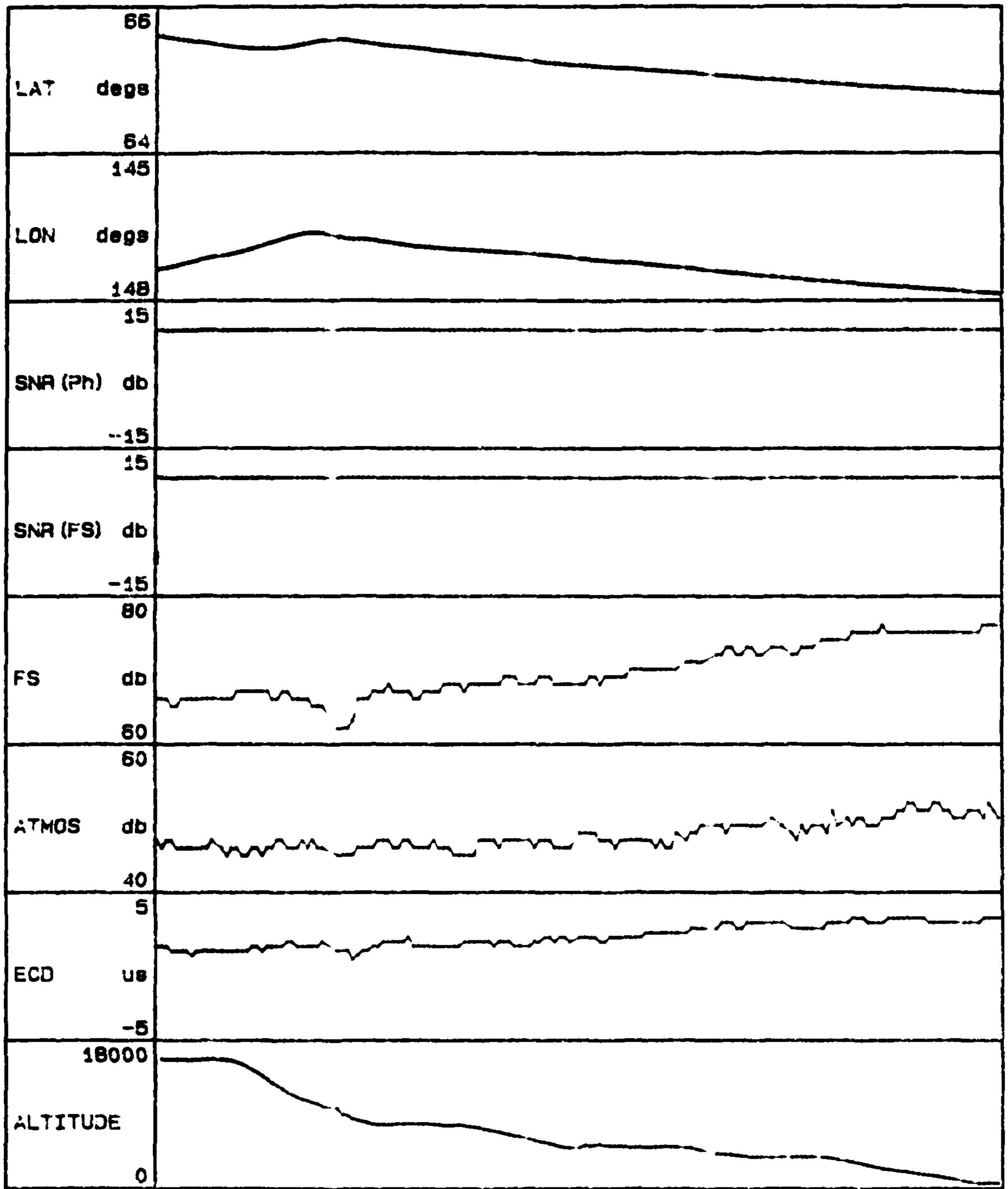

65
LAT degs
64
147
LON degs
150
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 20:53:19 - 21:16:29
STATION:7960 X RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/10/85 FILE: S09101


65
LAT degs
64
147
LON degs
150
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 20:53:19 - 21:16:29
STATION:7960 X RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/10/85 FILE: S09101


65
LAT degs
64
147
LON degs
150
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 20:53:19 - 21:16:29
STATION:9990 Y RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/10/85 FILE: S09102



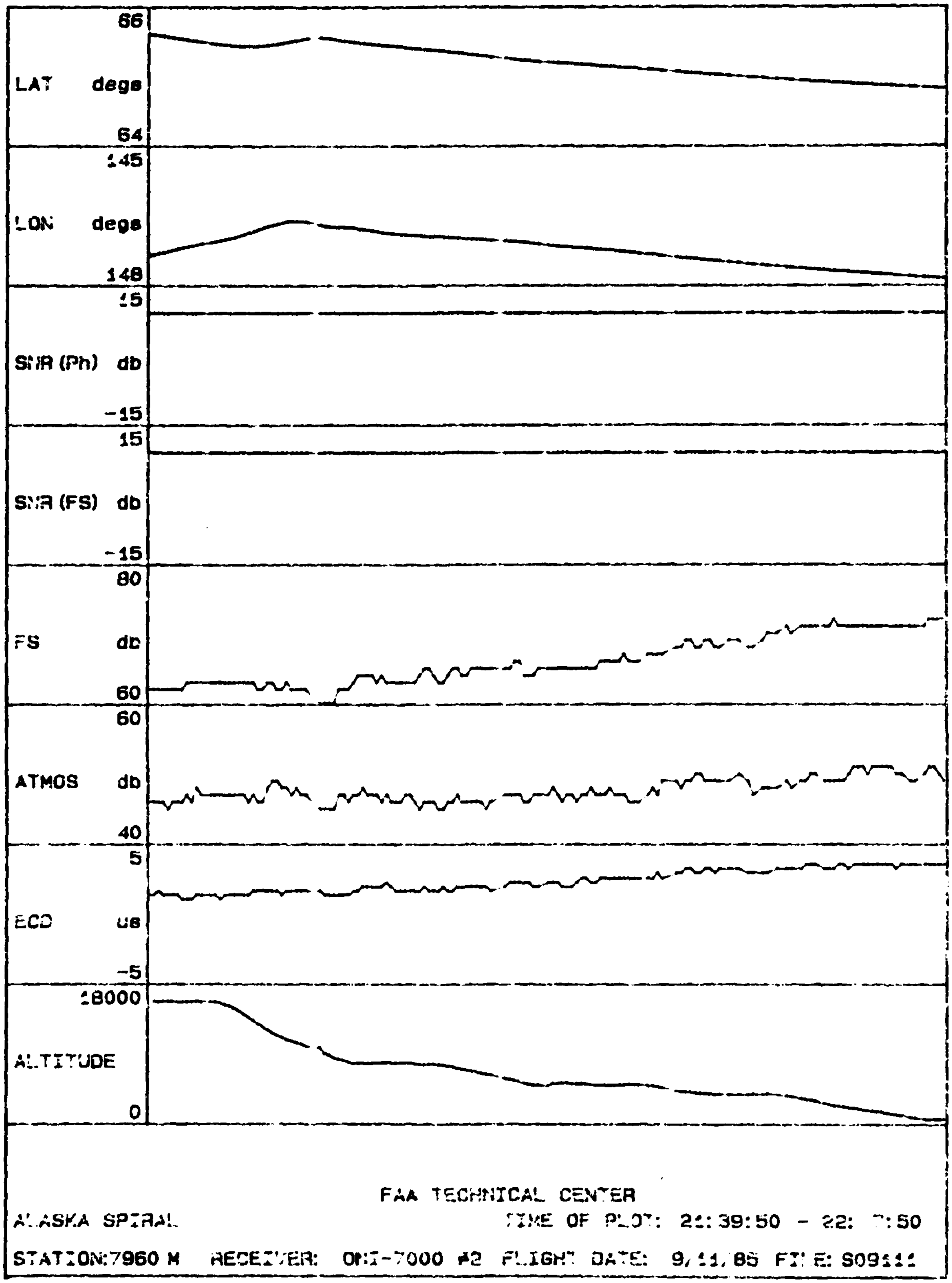
65
LAT degs
64
147
LON degs
150
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 20:53:19 - 21:16:29
STATION:9990 Y RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/10/85 FILE: S09102

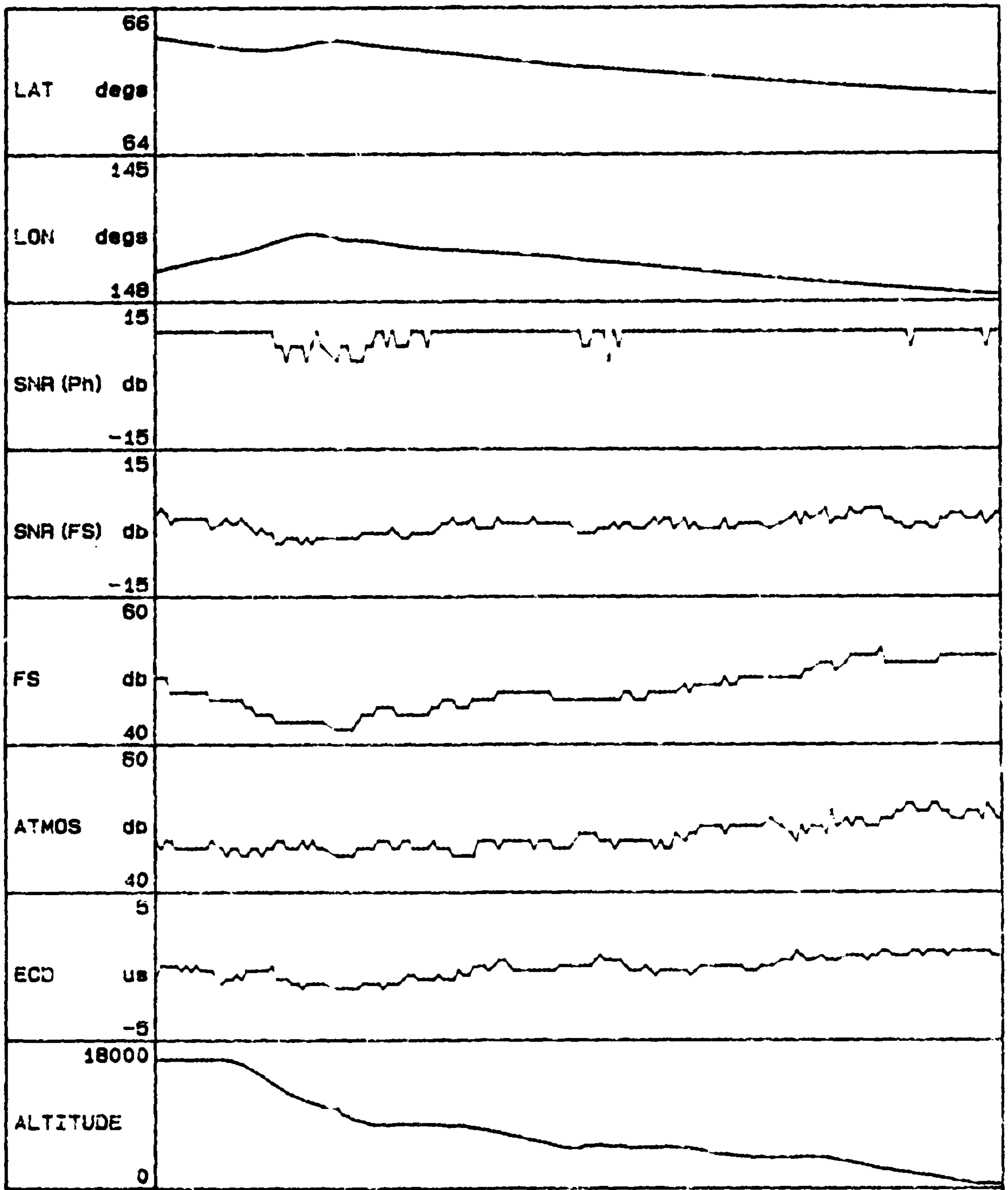


FAA TECHNICAL CENTER

ALASKA SPIRAL TIME OF PLOT: 21:39:50 - 22: 7:50

STATION:7960 M RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/11/85 FILE: S09111

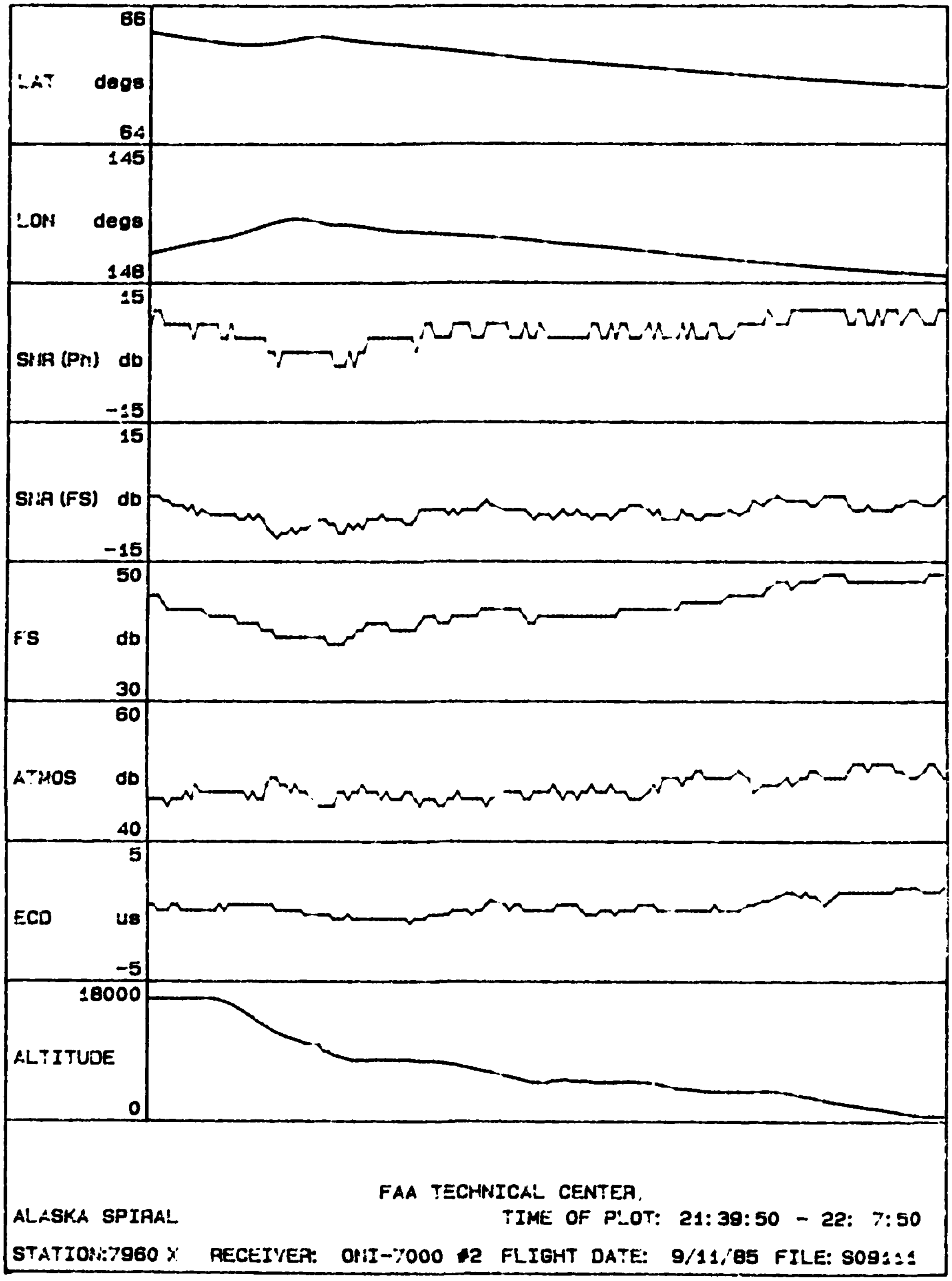

66
LAT degs
64
145
LON degs
148
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
80
FS db
60
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 21:39:50 - 22: :50
STATION:7960 M RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/11/85 FILE: S09111



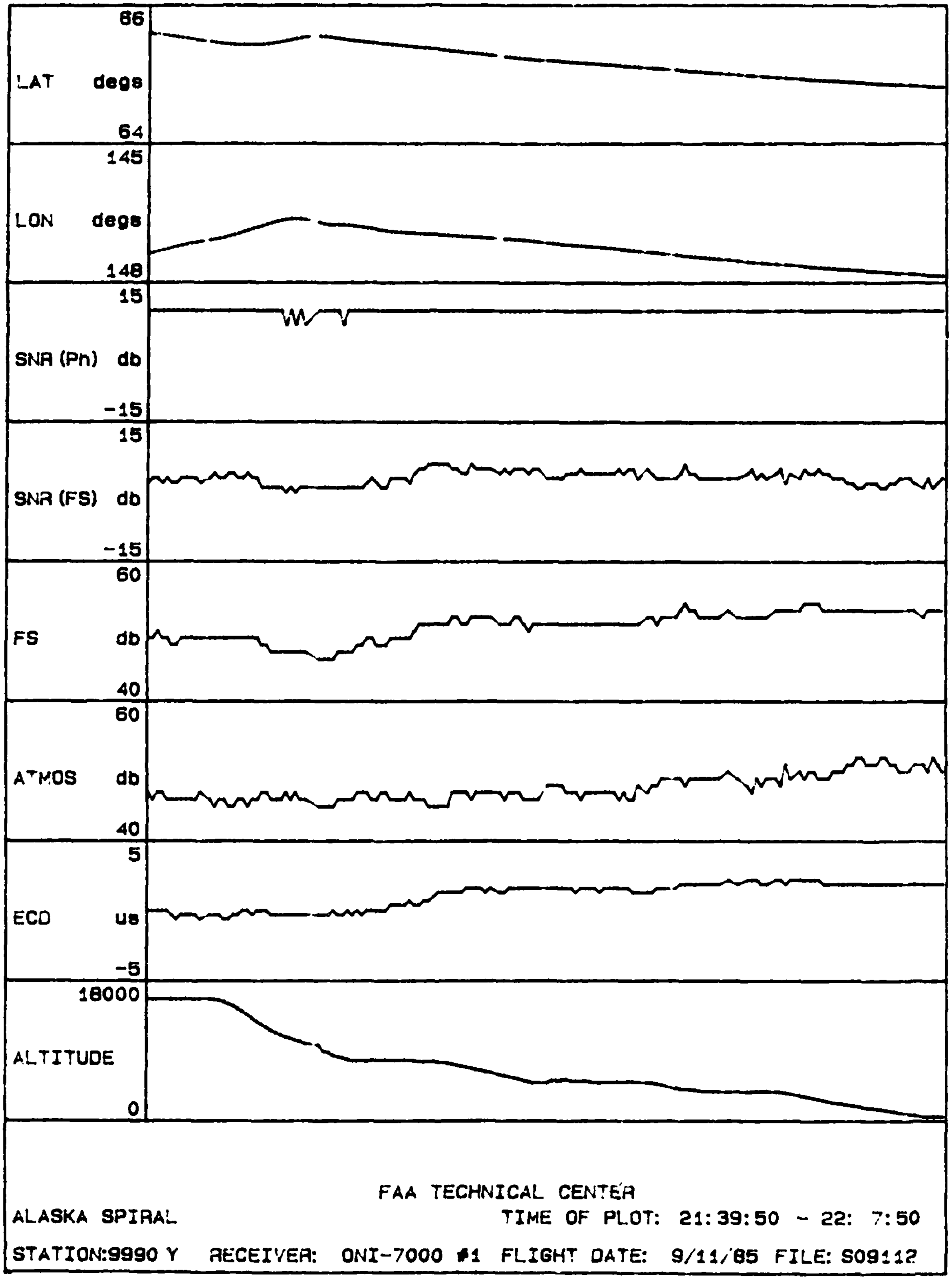
FAA TECHNICAL CENTER

ALASKA SPIRAL TIME OF PLOT: 21:39:50 - 22: 7:50

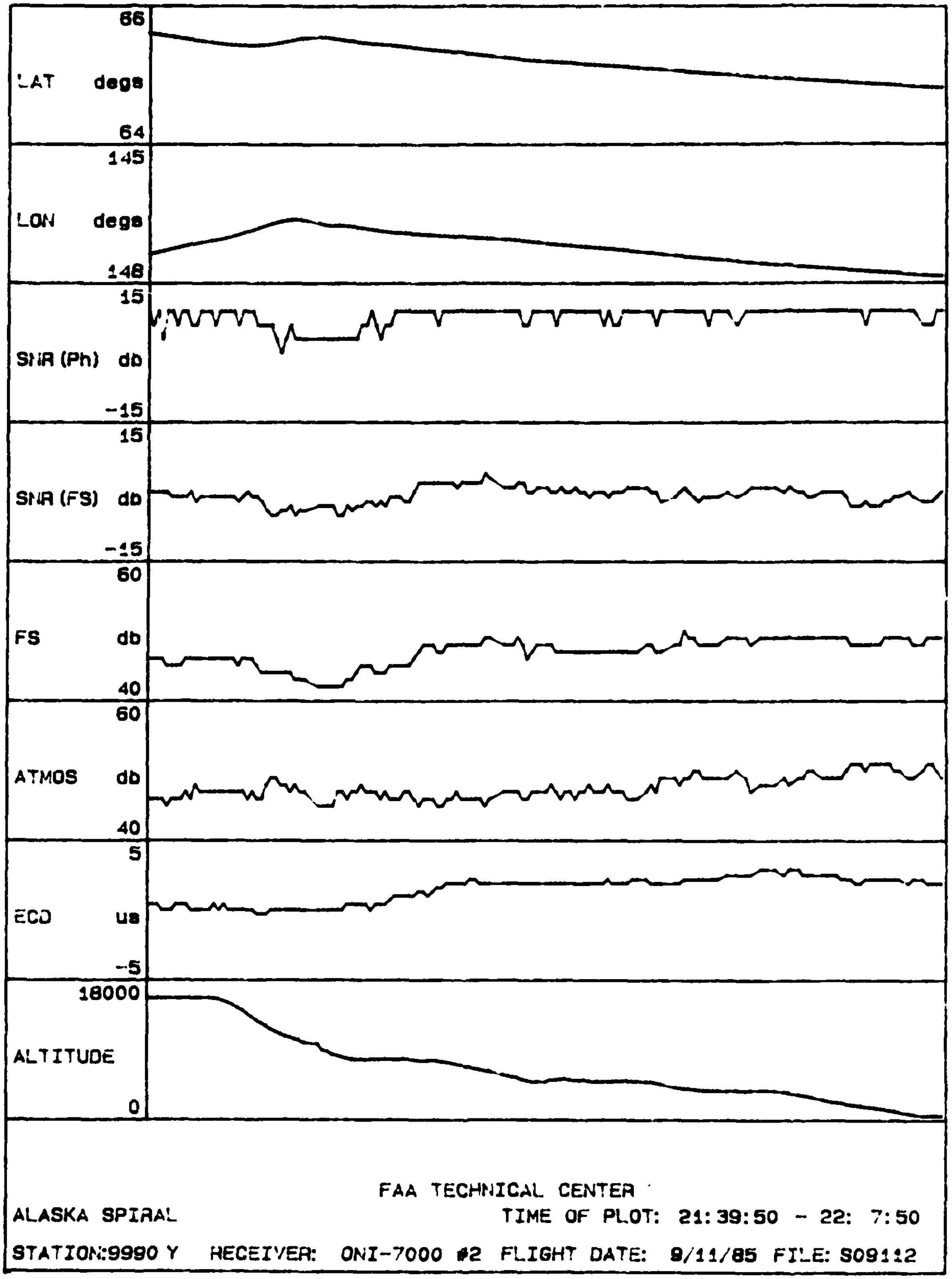
STATION:7960 X RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/11/85 FILE: S09111



66
LAT degs
64
145
LON degs
148
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
50
FS db
30
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER,
ALASKA SPIRAL
TIME OF PLOT: 21:39:50 - 22: 7:50
STATION:7960 X RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/11/85 FILE: S091



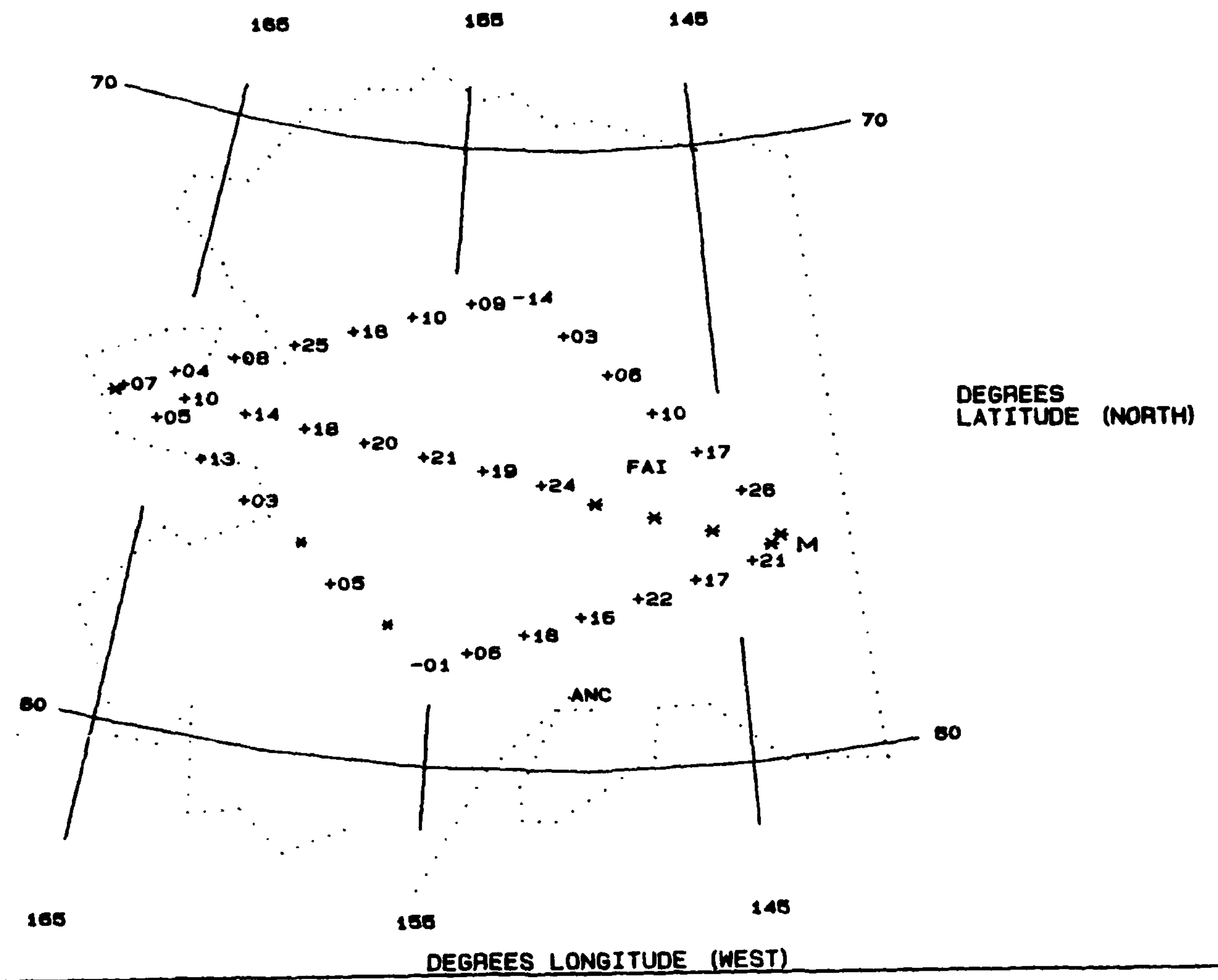
66
LAT degs
64
145
LON degs
148
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 21:39:50 - 22: 7:50
STATION:9990 Y RECEIVER: ONI-7000 #1 FLIGHT DATE: 9/11/85 FILE: S09112


66
LAT degs
64
145
LON degs
148
15
SNR (Ph) db
-15
15
SNR (FS) db
-15
60
FS db
40
60
ATMOS db
40
5
ECD us
-5
18000
ALTITUDE
0
FAA TECHNICAL CENTER
ALASKA SPIRAL
TIME OF PLOT: 21:39:50 - 22: 7:50
STATION:9990 Y RECEIVER: ONI-7000 #2 FLIGHT DATE: 9/11/85 FILE: S09112

APPENDIX C

PLOTS OF ECD VALUES

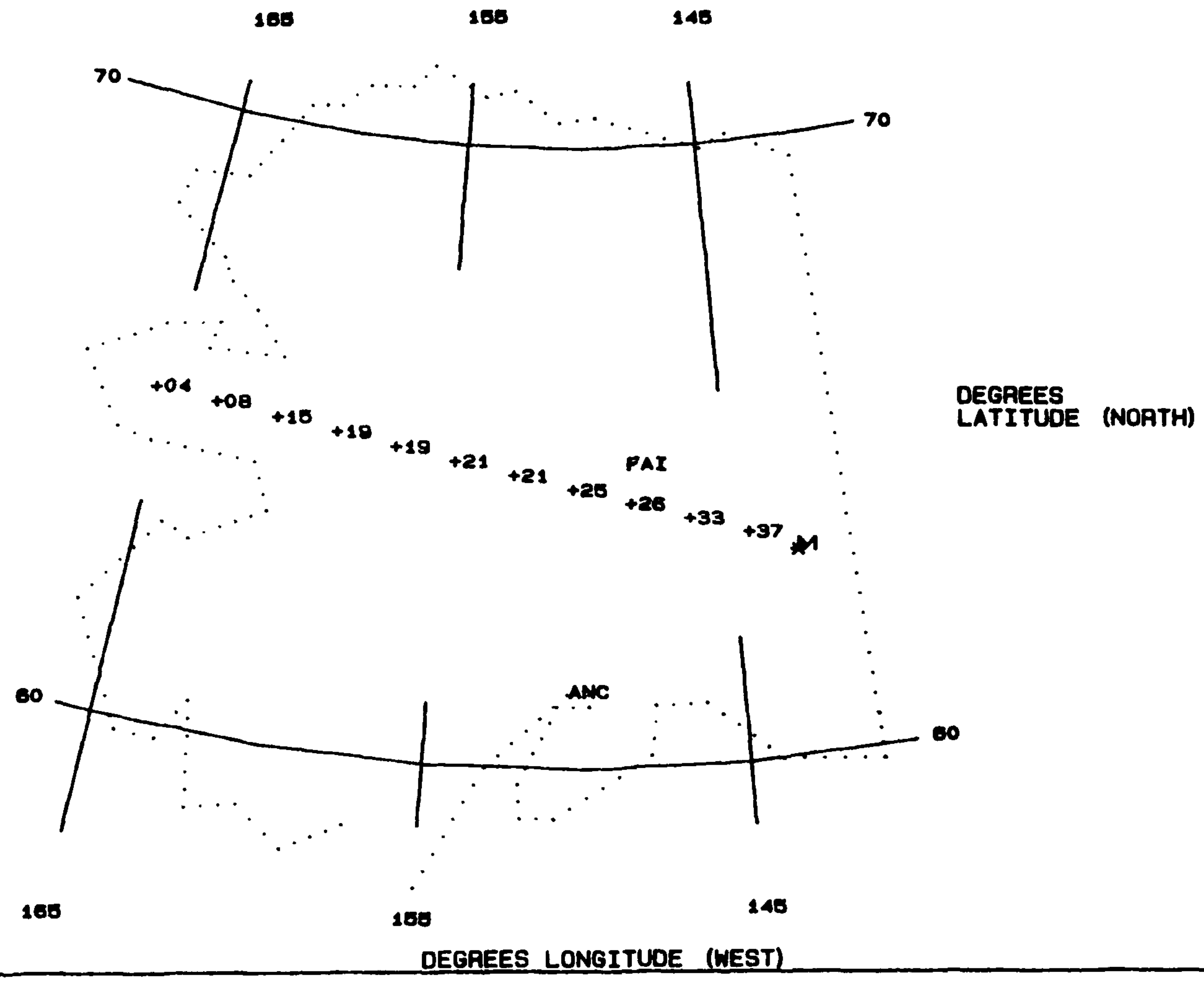
The plots in this appendix give the envelope-to-cycle difference (ECD) values in microseconds (μs) collected during both summer and winter flights in Alaska. Information listed at the bottom of each plot includes: receiver number, chain and station involved, and season the data were collected.



RECEIVER: ONI-7000 #1
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

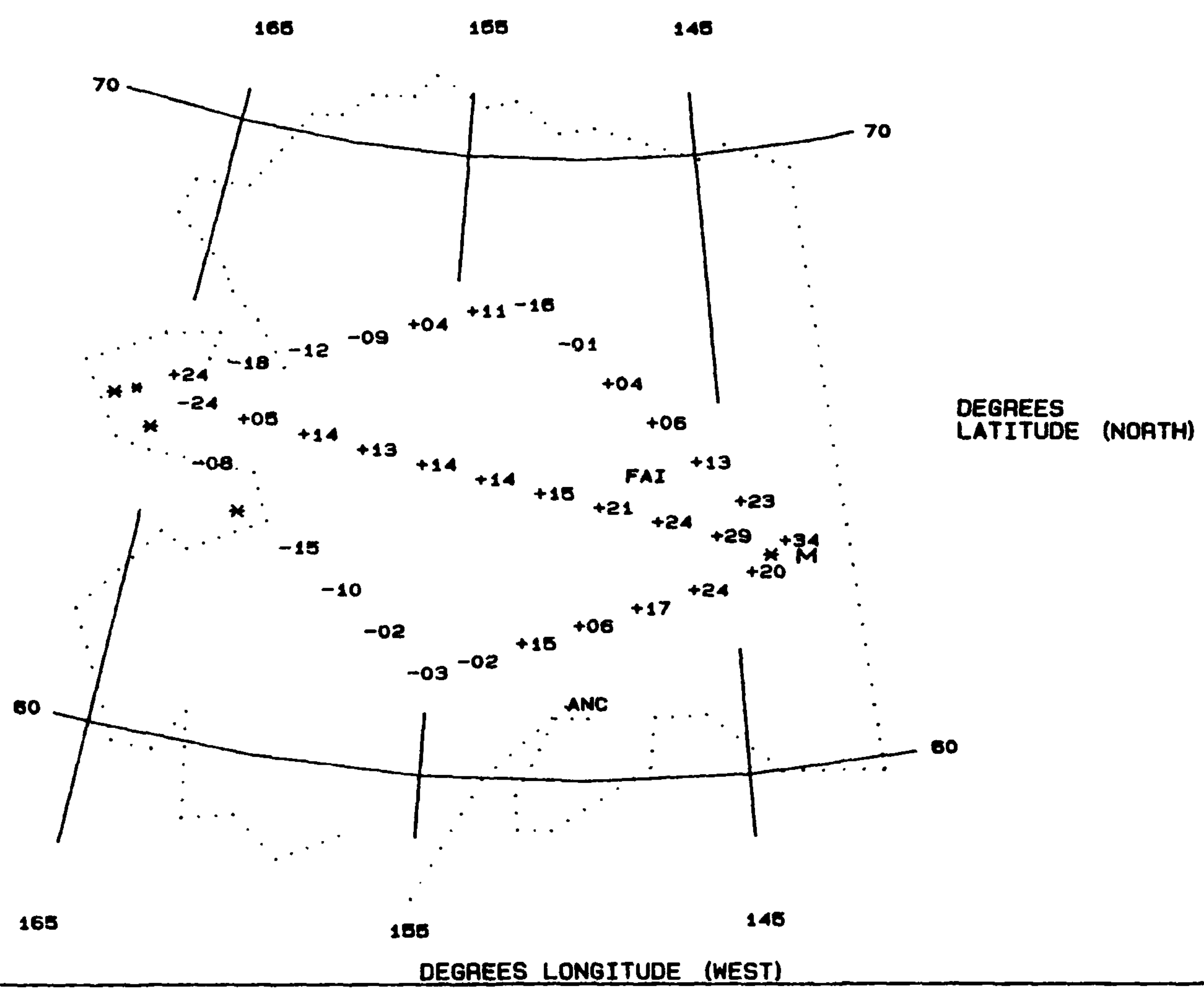
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #1
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

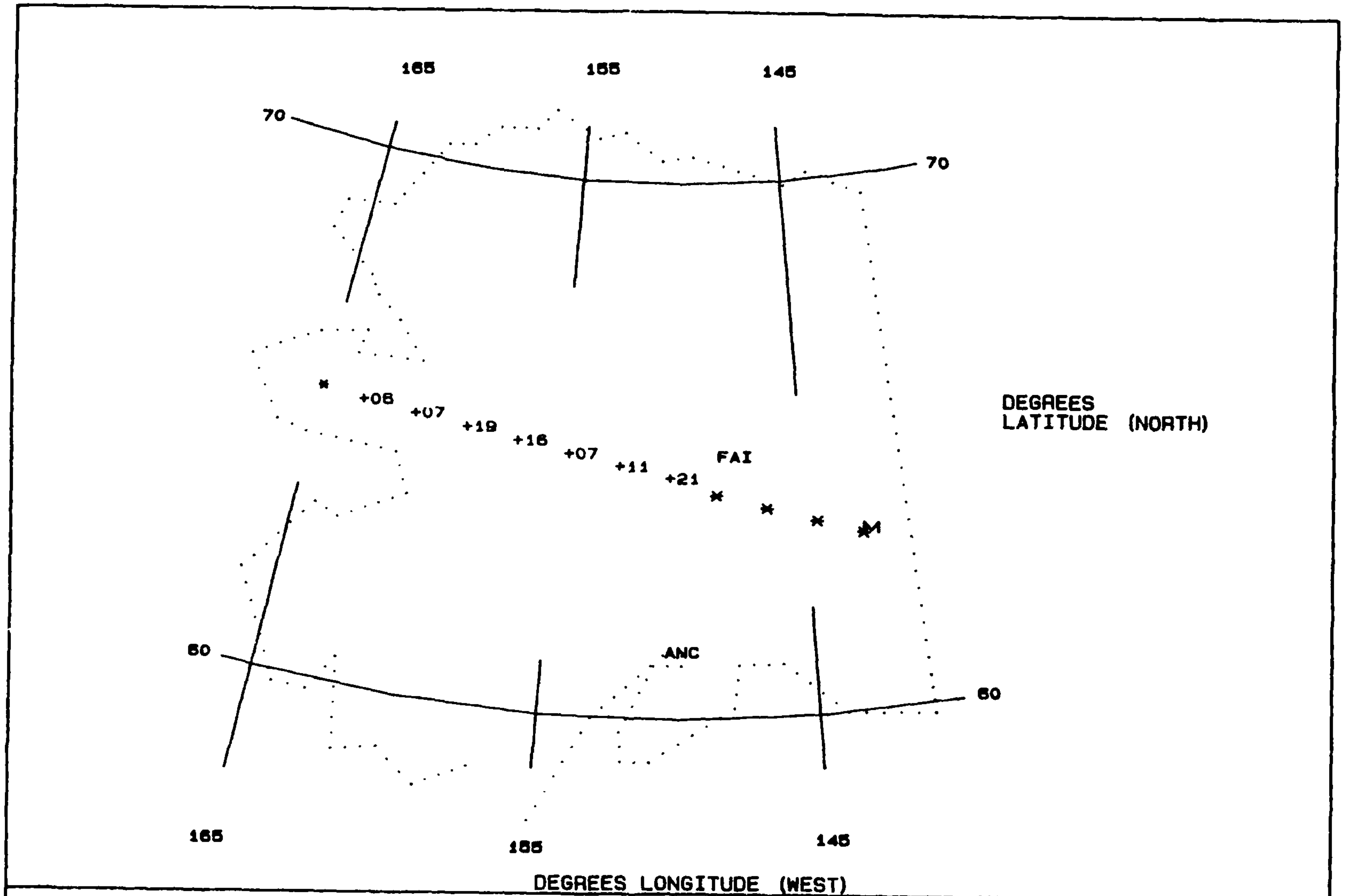
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #1
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

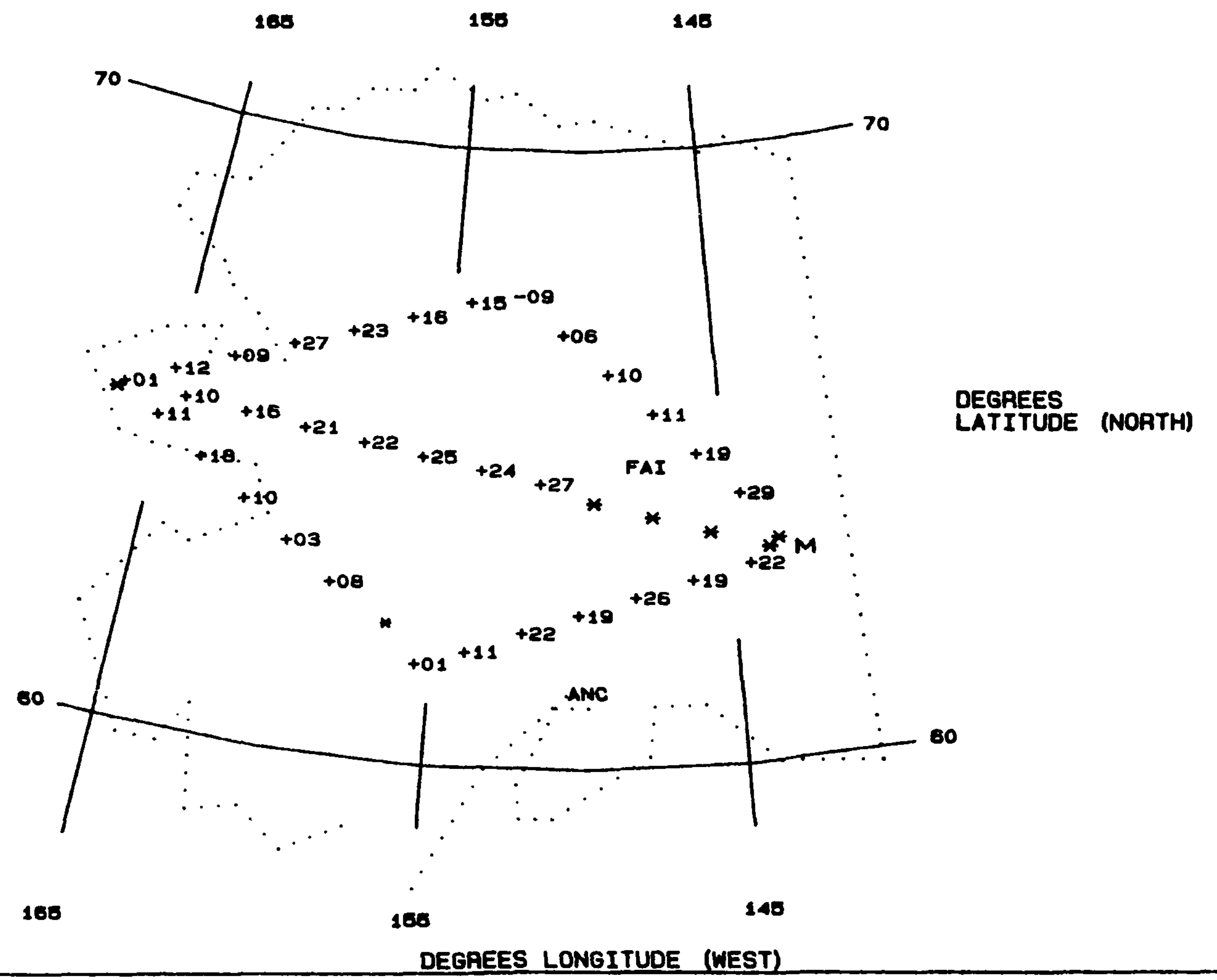
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #1
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

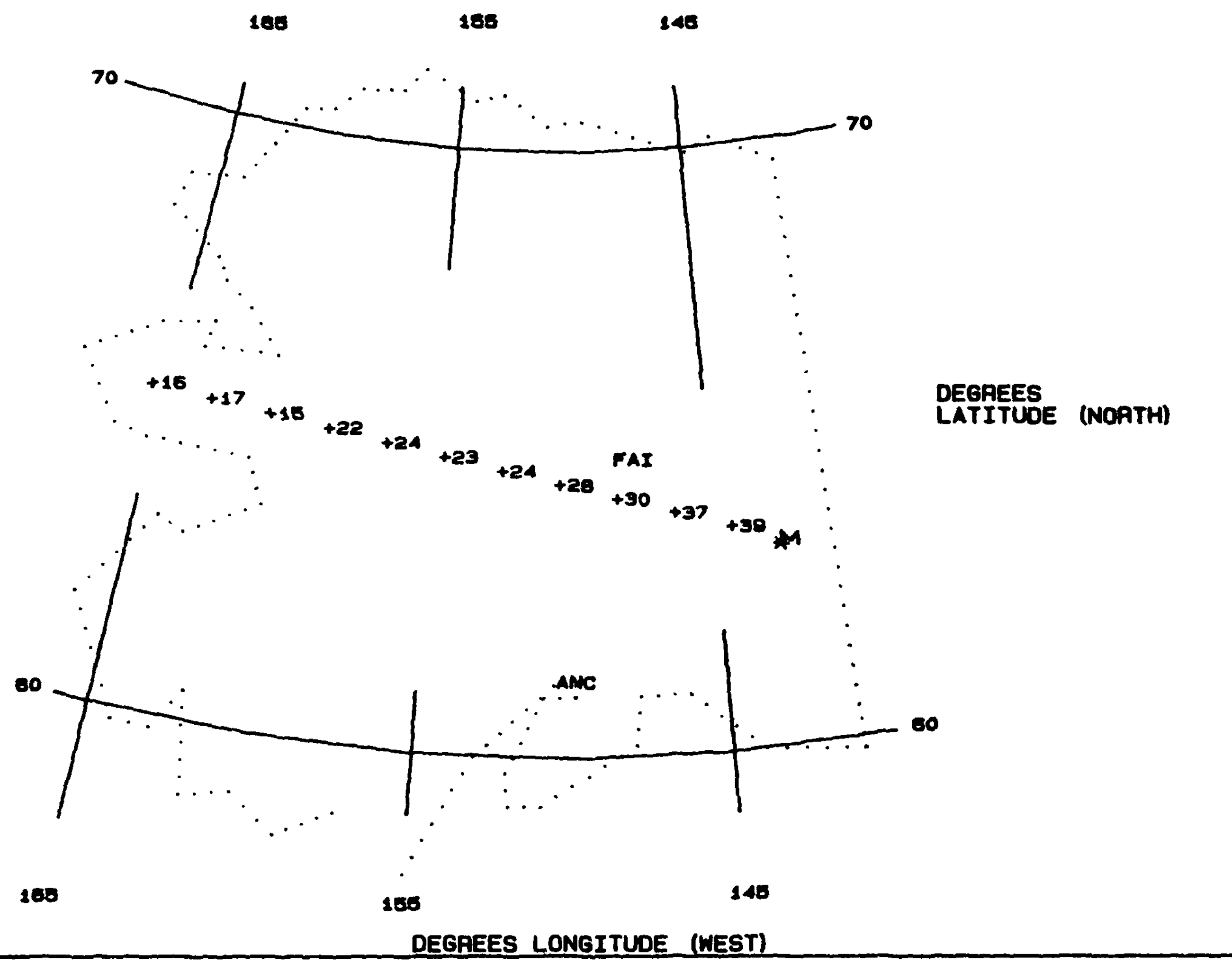
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #2
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

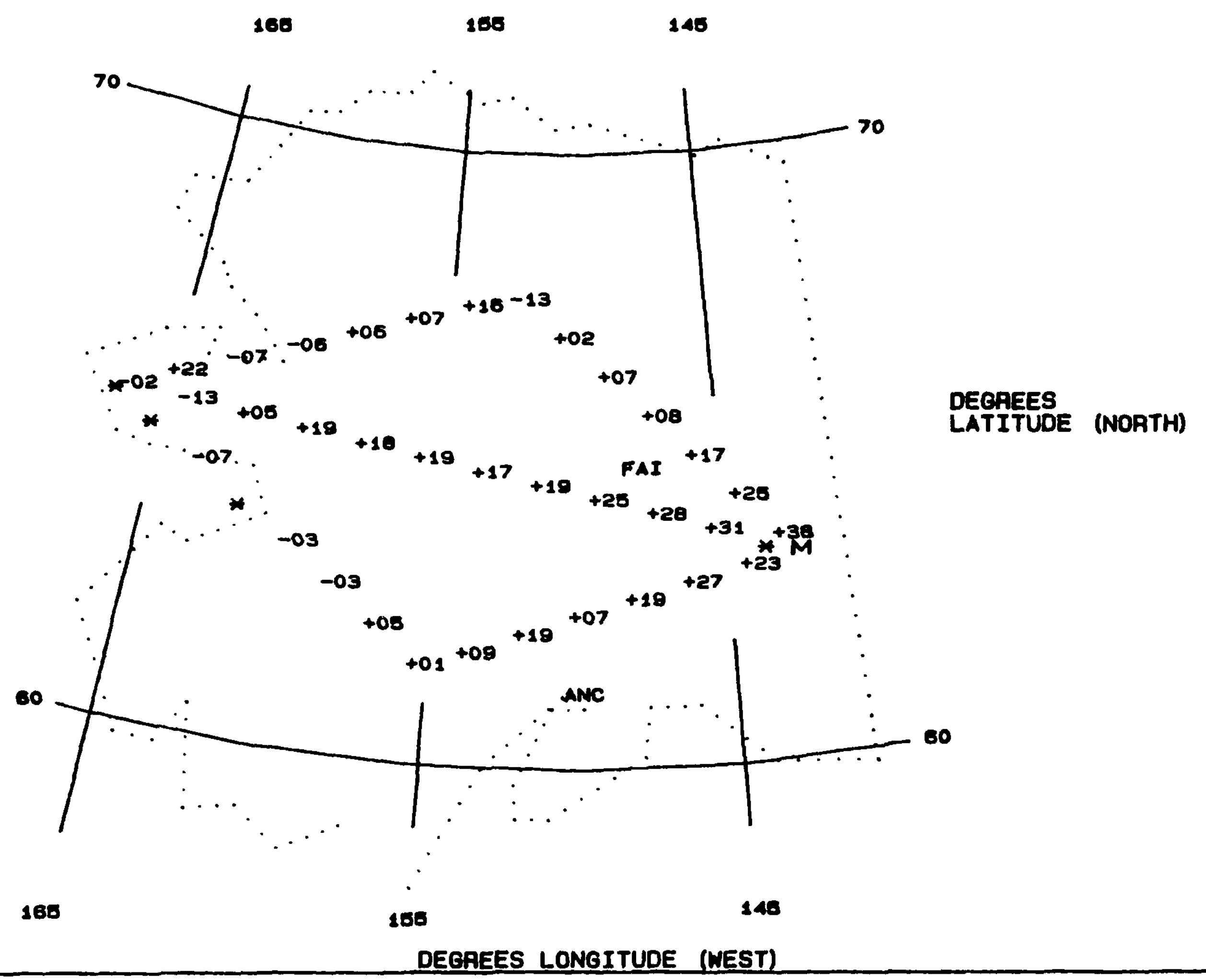
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #2
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

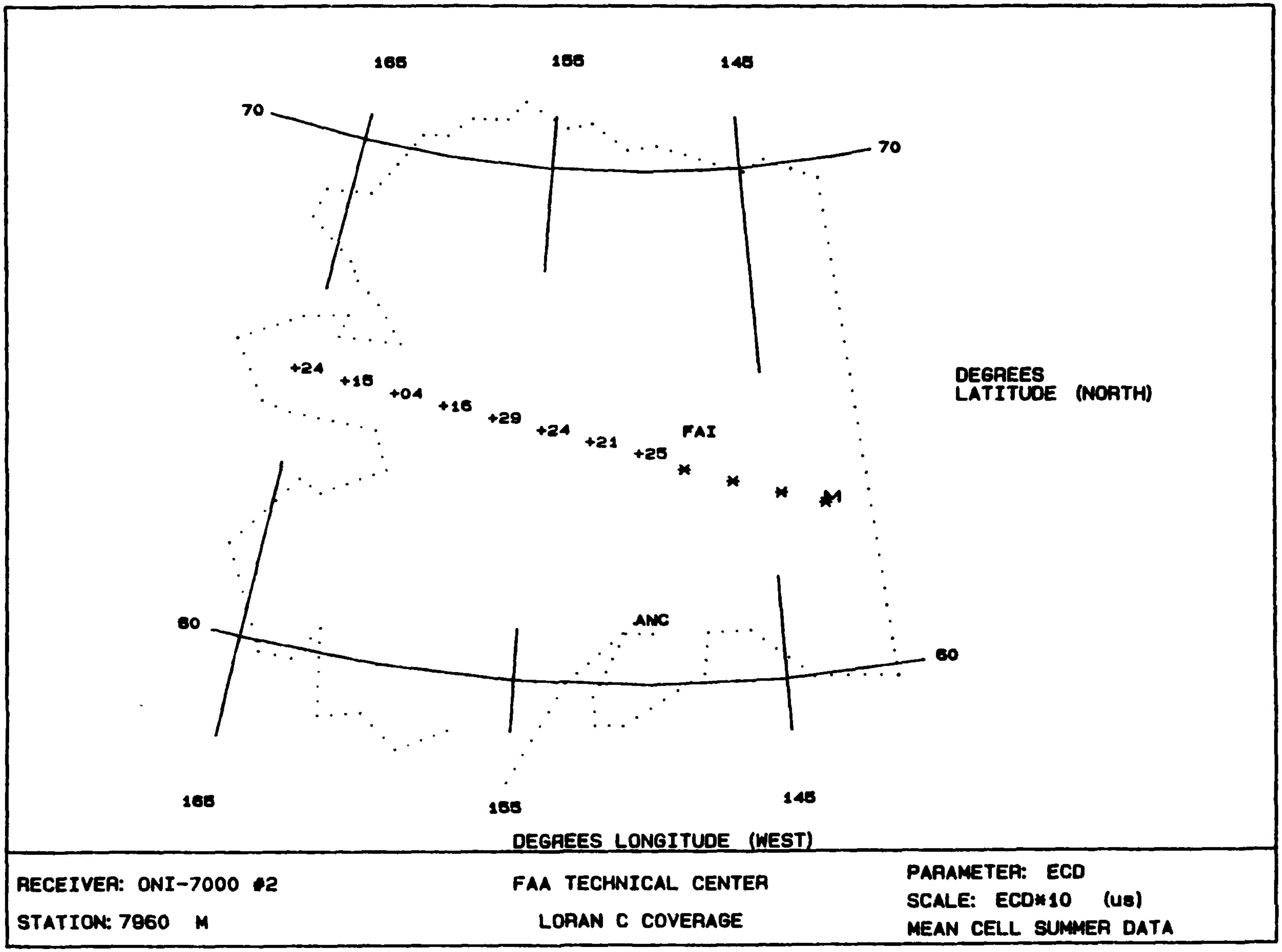
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



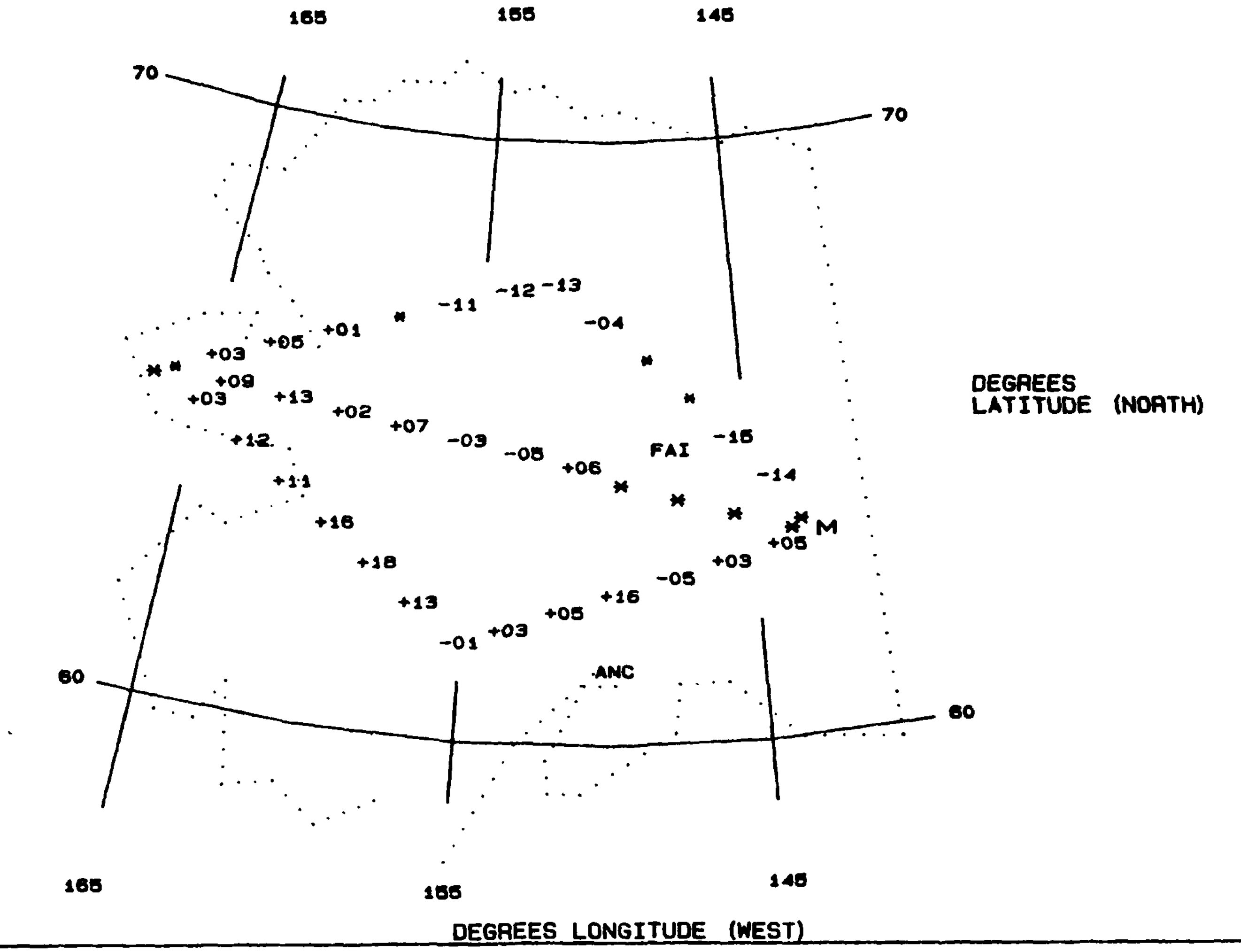
RECEIVER: ONI-7000 #2
STATION: 7960 M

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



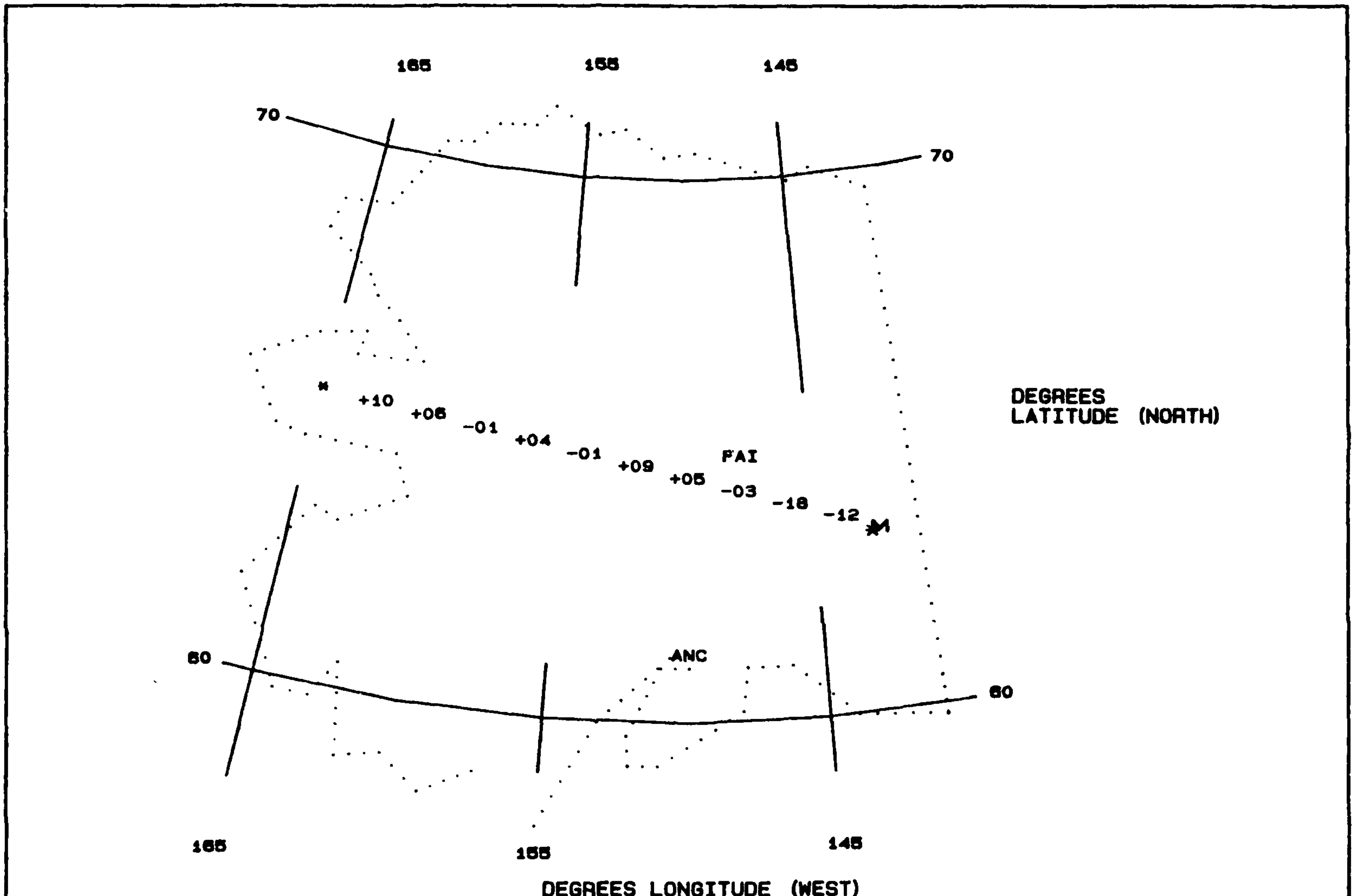
165
155
145
70
70
+24
+15
+04
+16
+29
+24
+21
+25
FAI
DEGREES
LATITUDE (NORTH)
ANC
60
60
165
155
145
DEGREES LONGITUDE (WEST)
RECEIVER: ONI-7000 #2
STATION: 7960 M
FAA TECHNICAL CENTER
LORAN C COVERAGE
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #1
STATION: 7960 X

FAA TECHNICAL CENTER
LORAN C COVERAGE

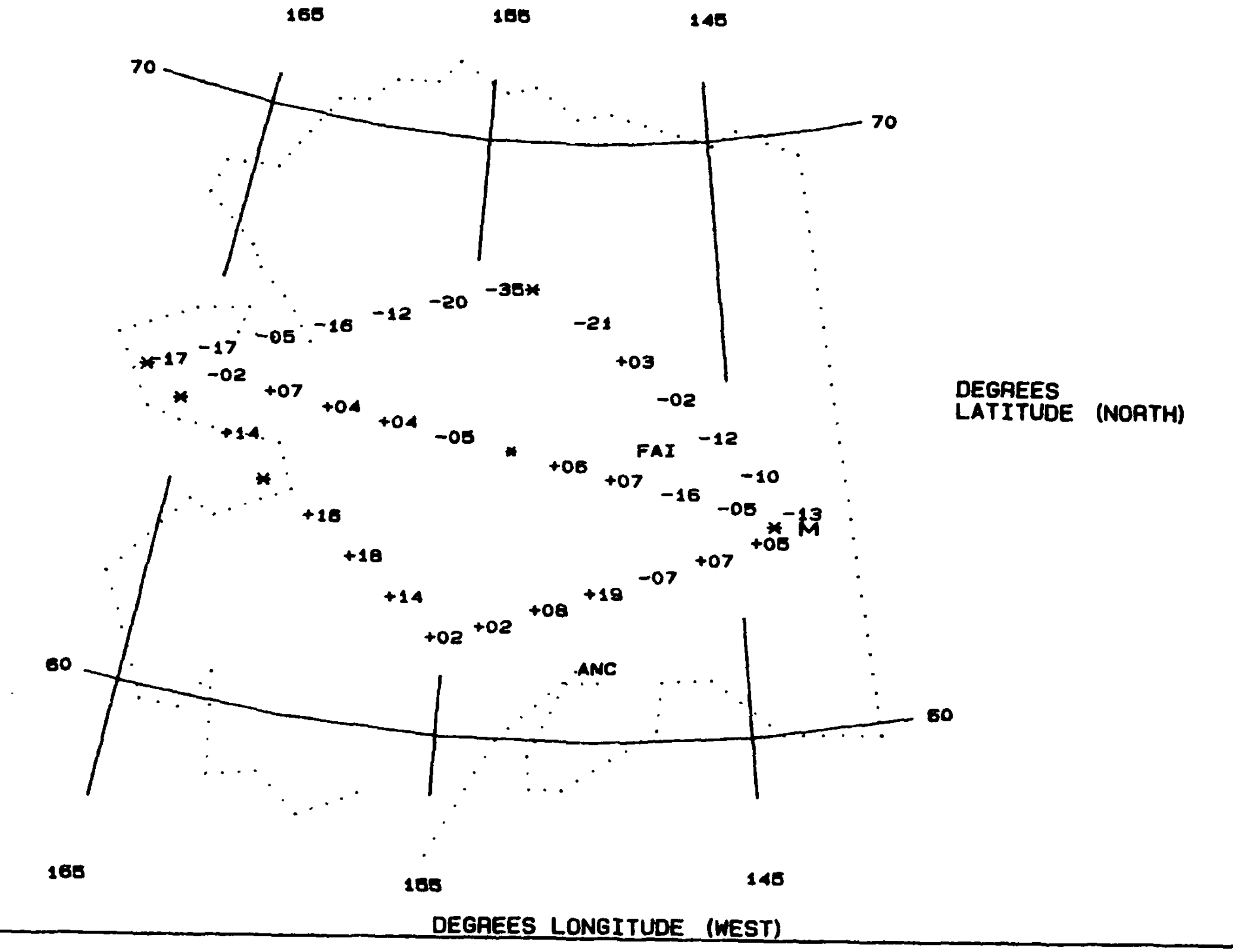
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



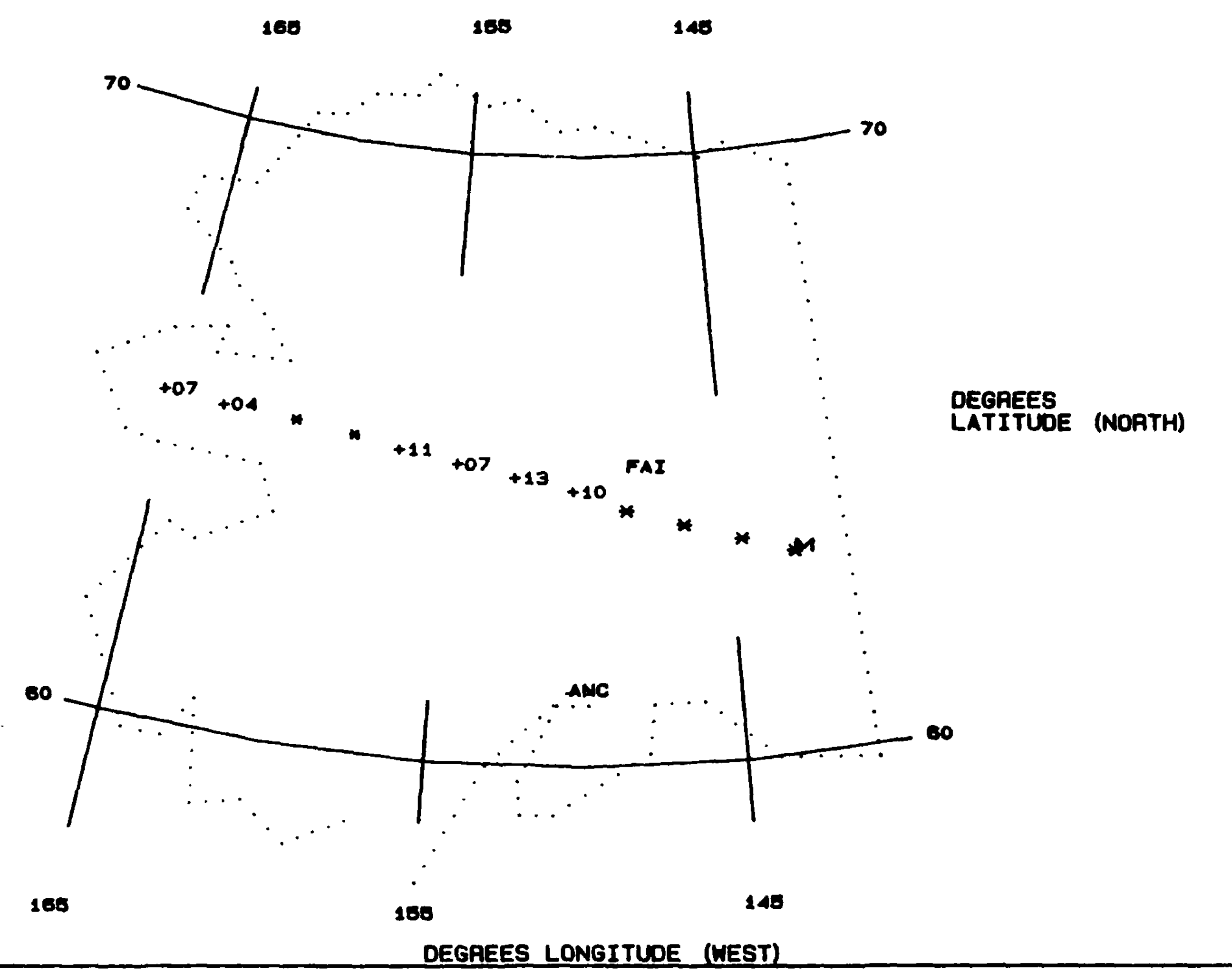
RECEIVER: ONI-7000 #1
STATION: 7960 X

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



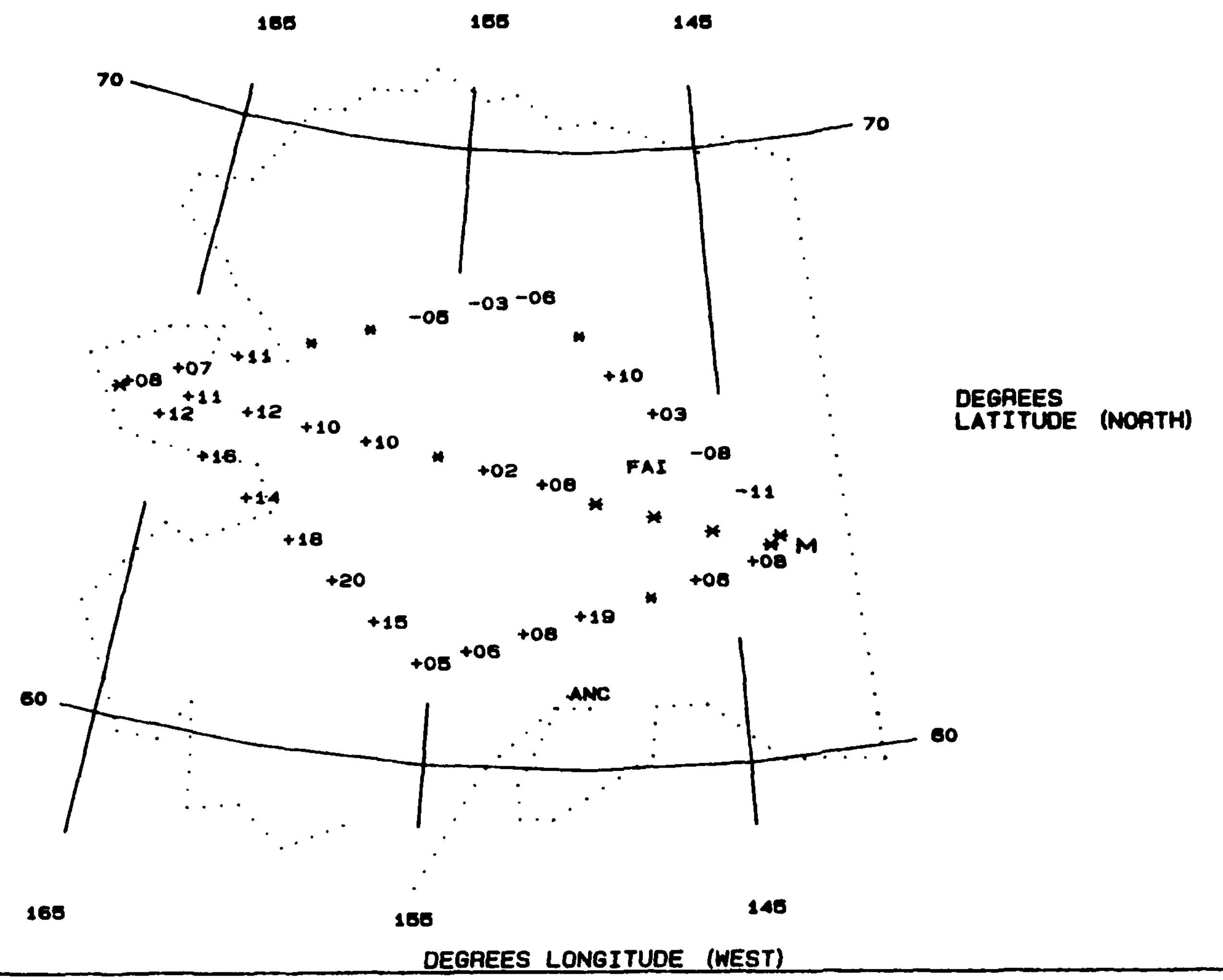
RECEIVER: ONI-7000 #1	FAA TECHNICAL CENTER	PARAMETER: ECD
STATION: 7960 X	LORAN C COVERAGE	SCALE: ECD*10 (us)
		MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #1
STATION: 7960 X

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #2	FAA TECHNICAL CENTER	PARAMETER: ECD
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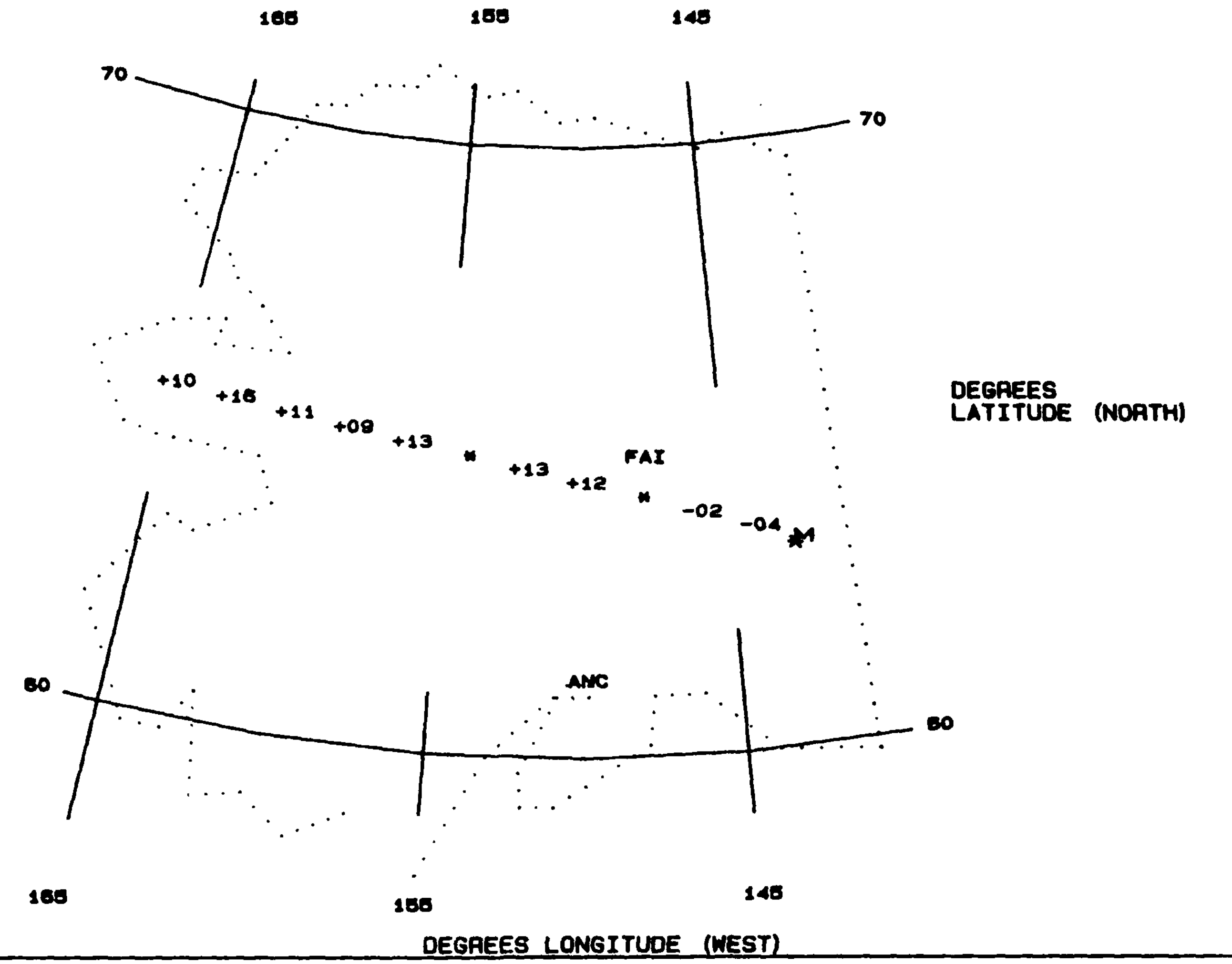
STATION: 7960 X	LORAN C COVERAGE	MEAN CELL WINTER DATA



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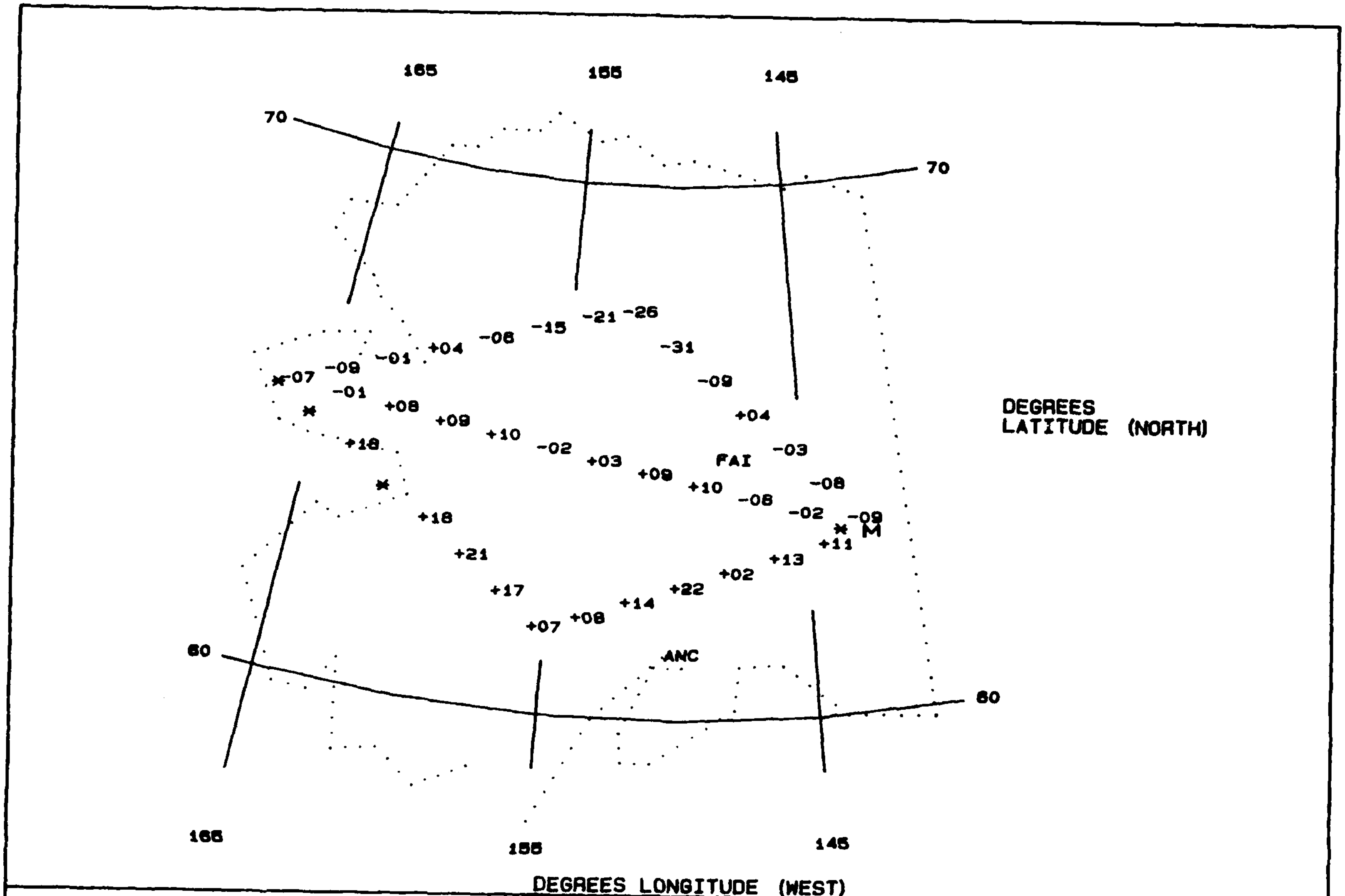
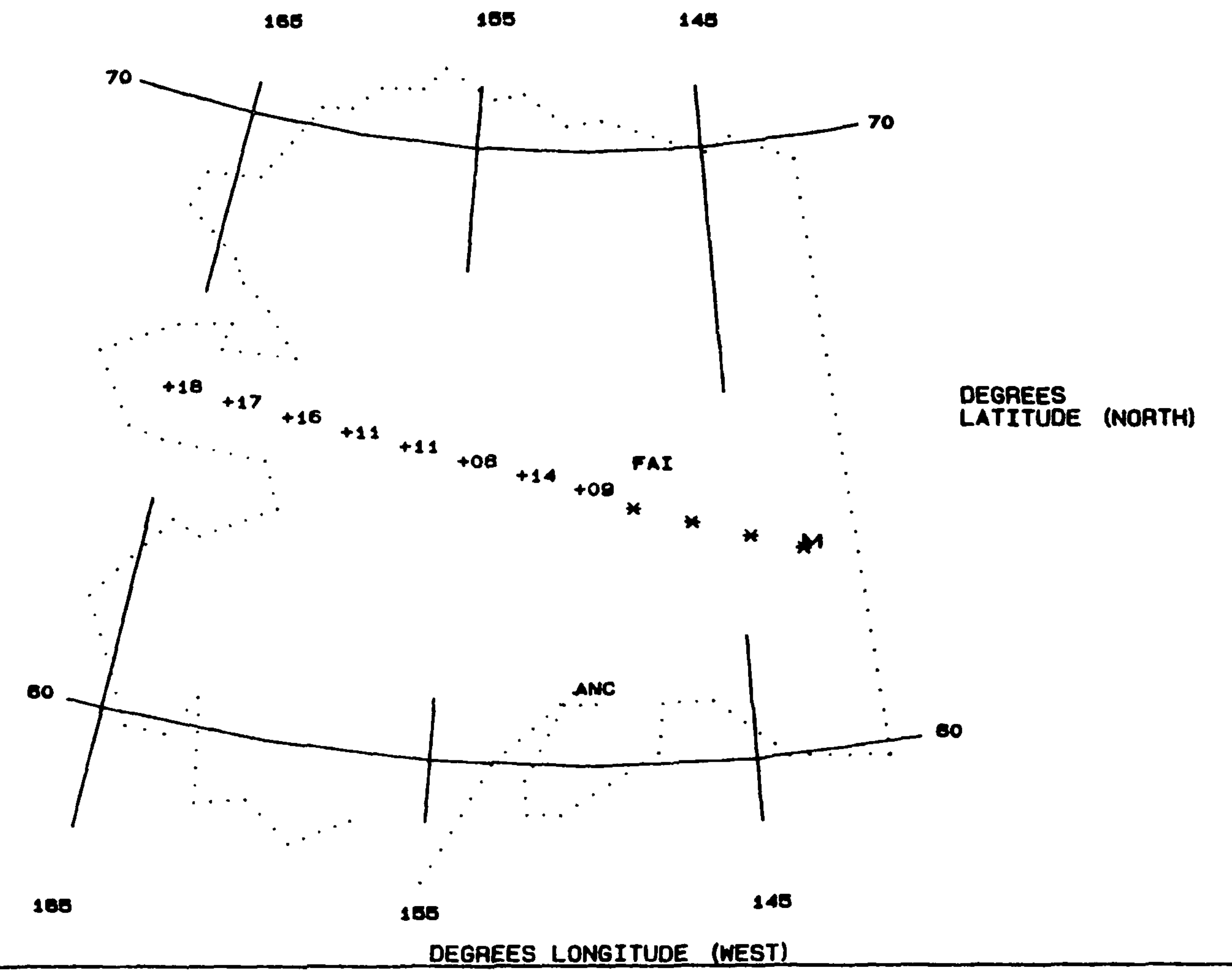


RECEIVER: ONI-7000 #2
STATION: 7960 X

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #2
STATION: 7960 X

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
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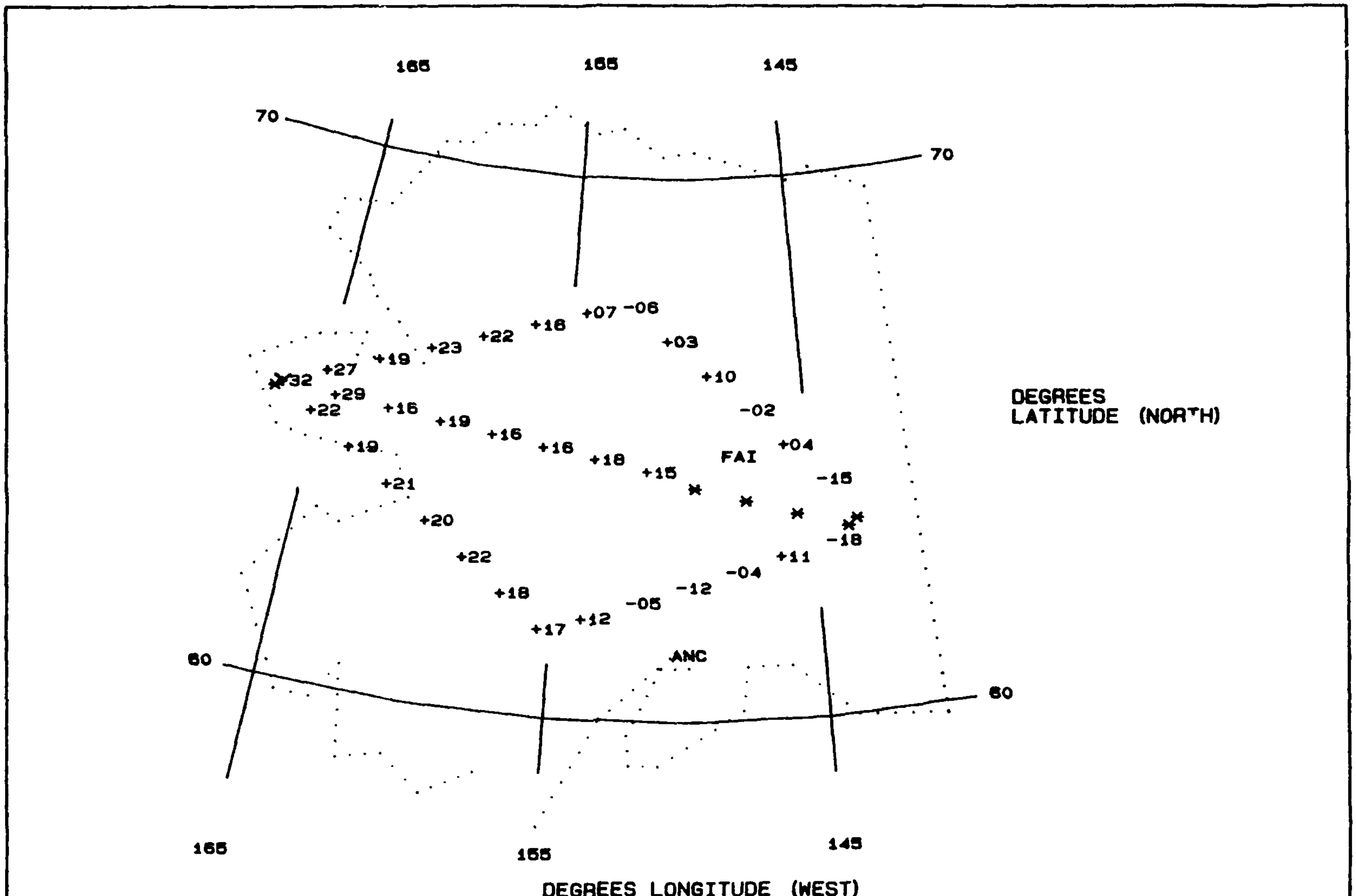
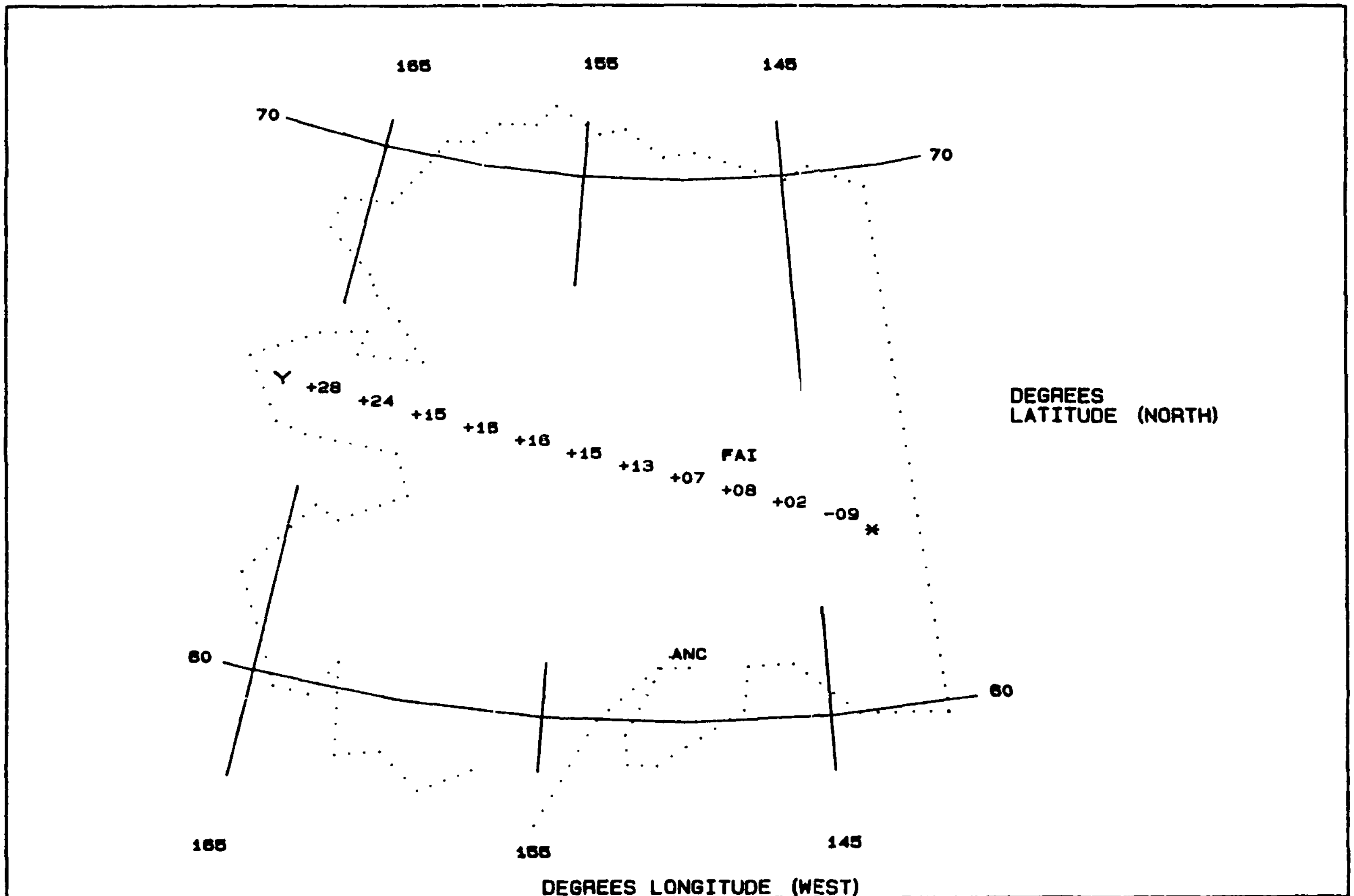


RECEIVER: ONI-7000 #1
STATION: 9990 Y

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #1	FAA TECHNICAL CENTER	PARAMETER: ECD
STATION: 9990 Y	LORAN C COVERAGE	SCALE: ECD*10 (us)
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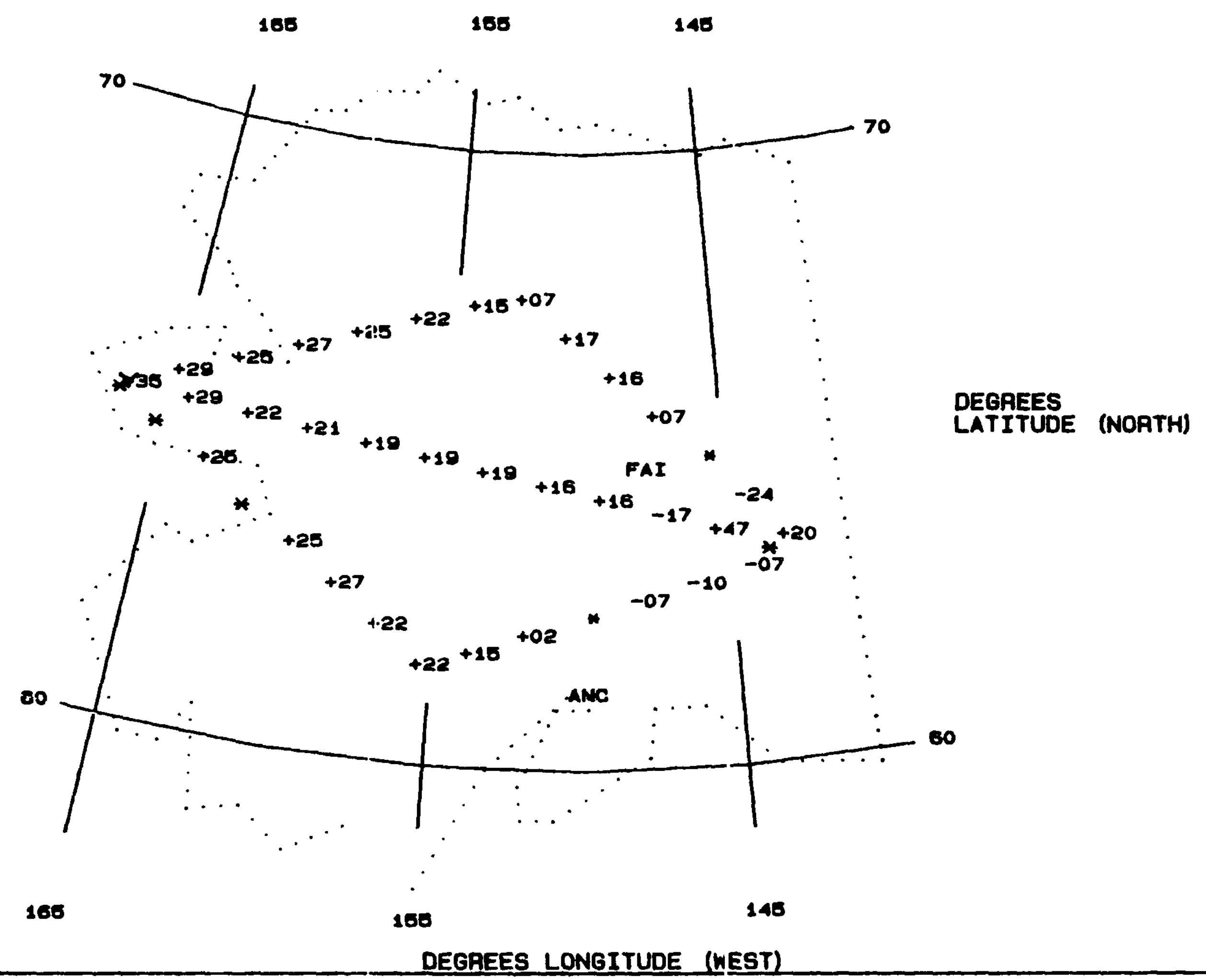

RECEIVER: ONI-7000 #1
STATION: 9990 Y

FAA TECHNICAL CENTER
LORAN C COVERAGE

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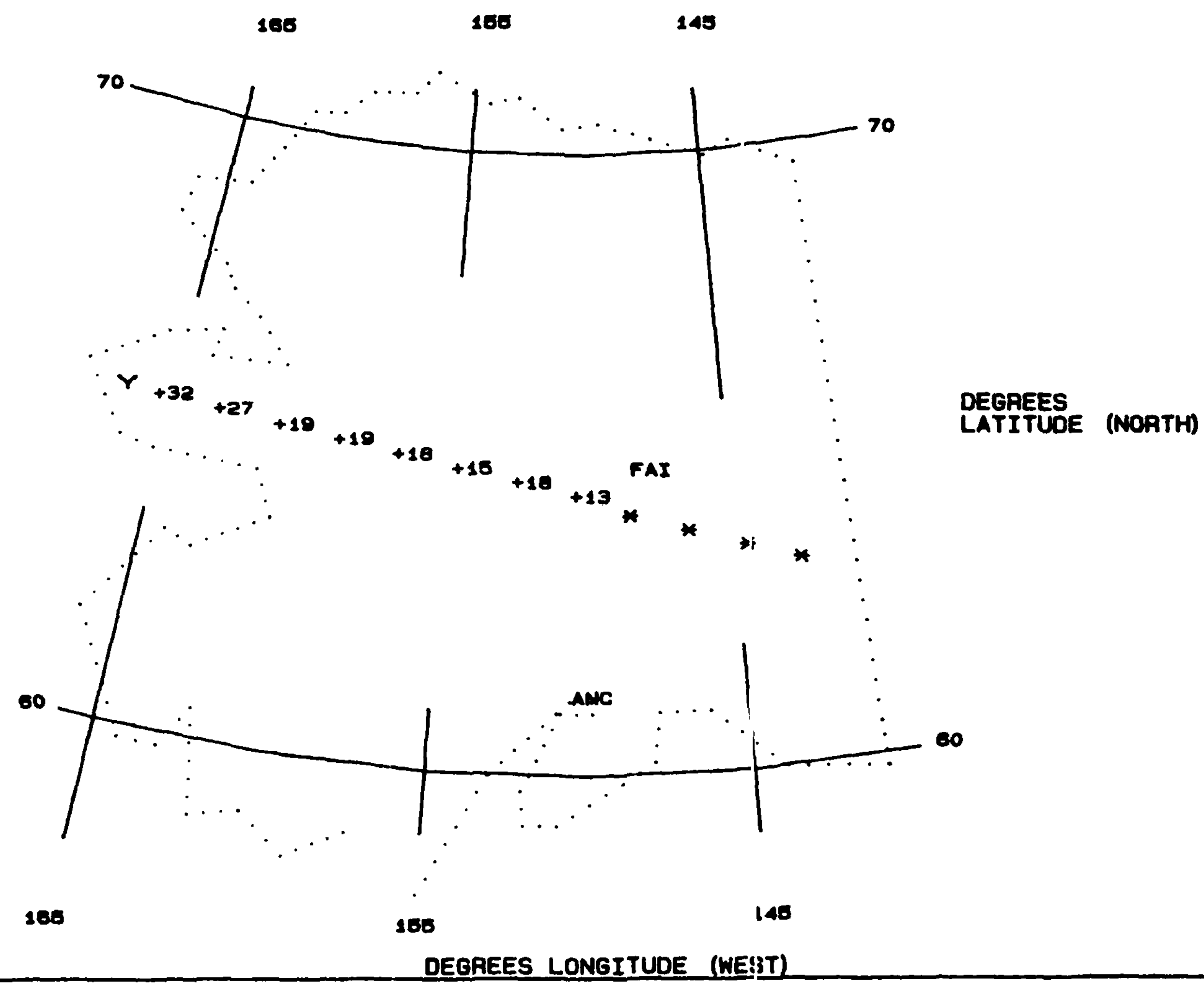
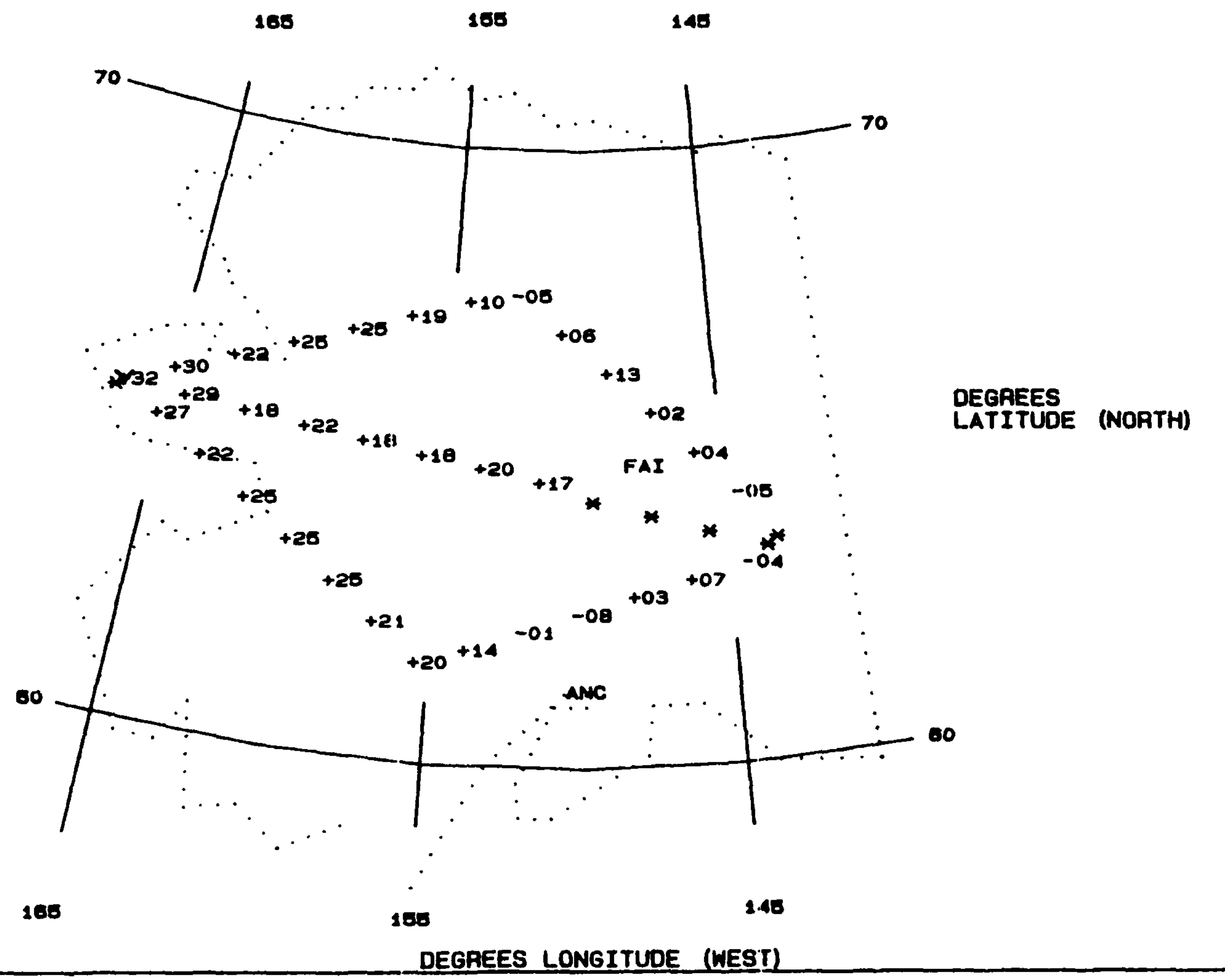


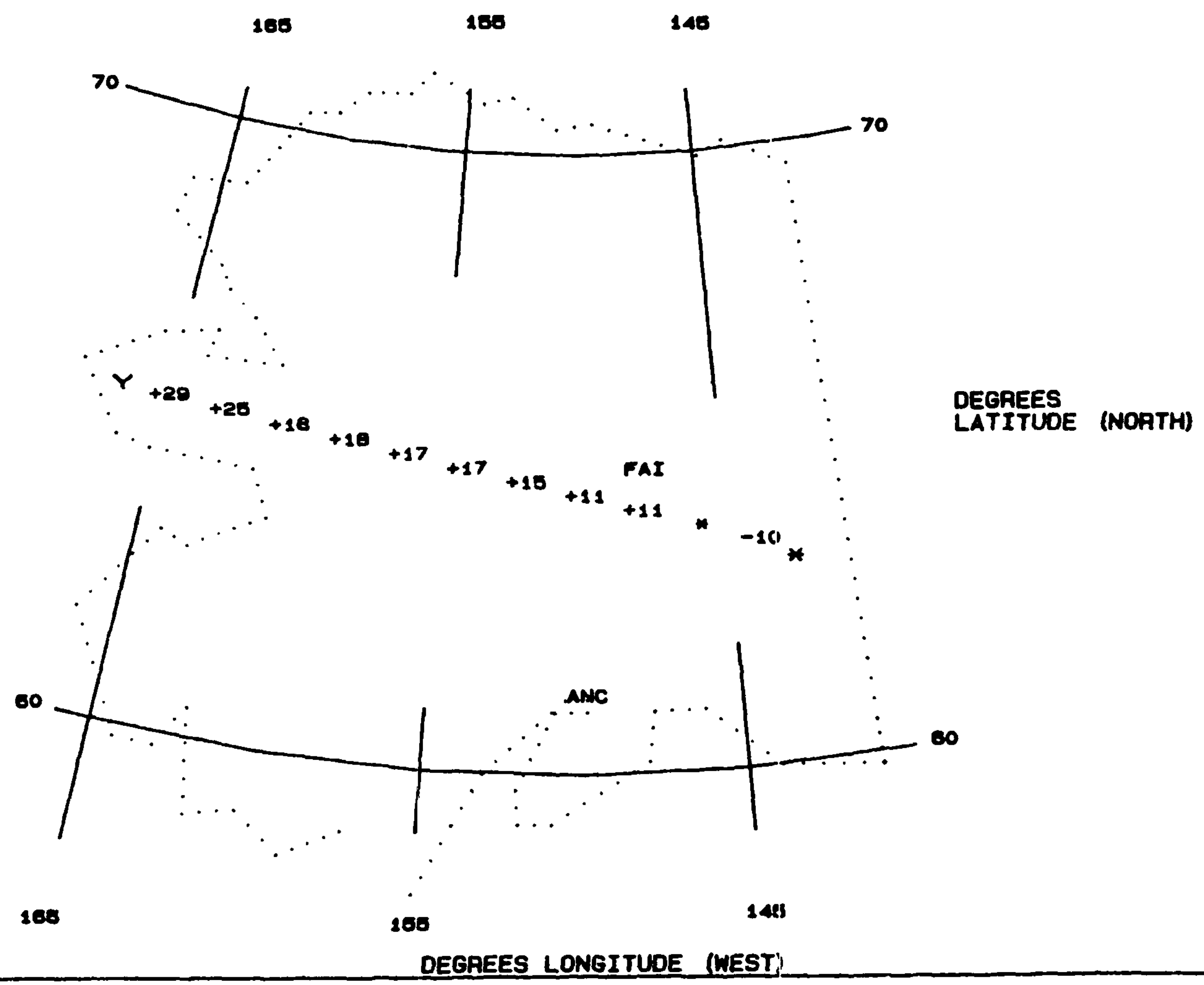
RECEIVER: ONI-7000 #1	FAA TECHNICAL CENTER	PARAMETER: ECD
STATION: 9990 Y	LORAN C COVERAGE	SCALE: ECD*10 (us)
		MEAN CELL SUMMER DATA



RECEIVER: ONI-7000 #2
STATION: 9990 Y

FAA TECHNICAL CENTER
LORAN C COVERAGE

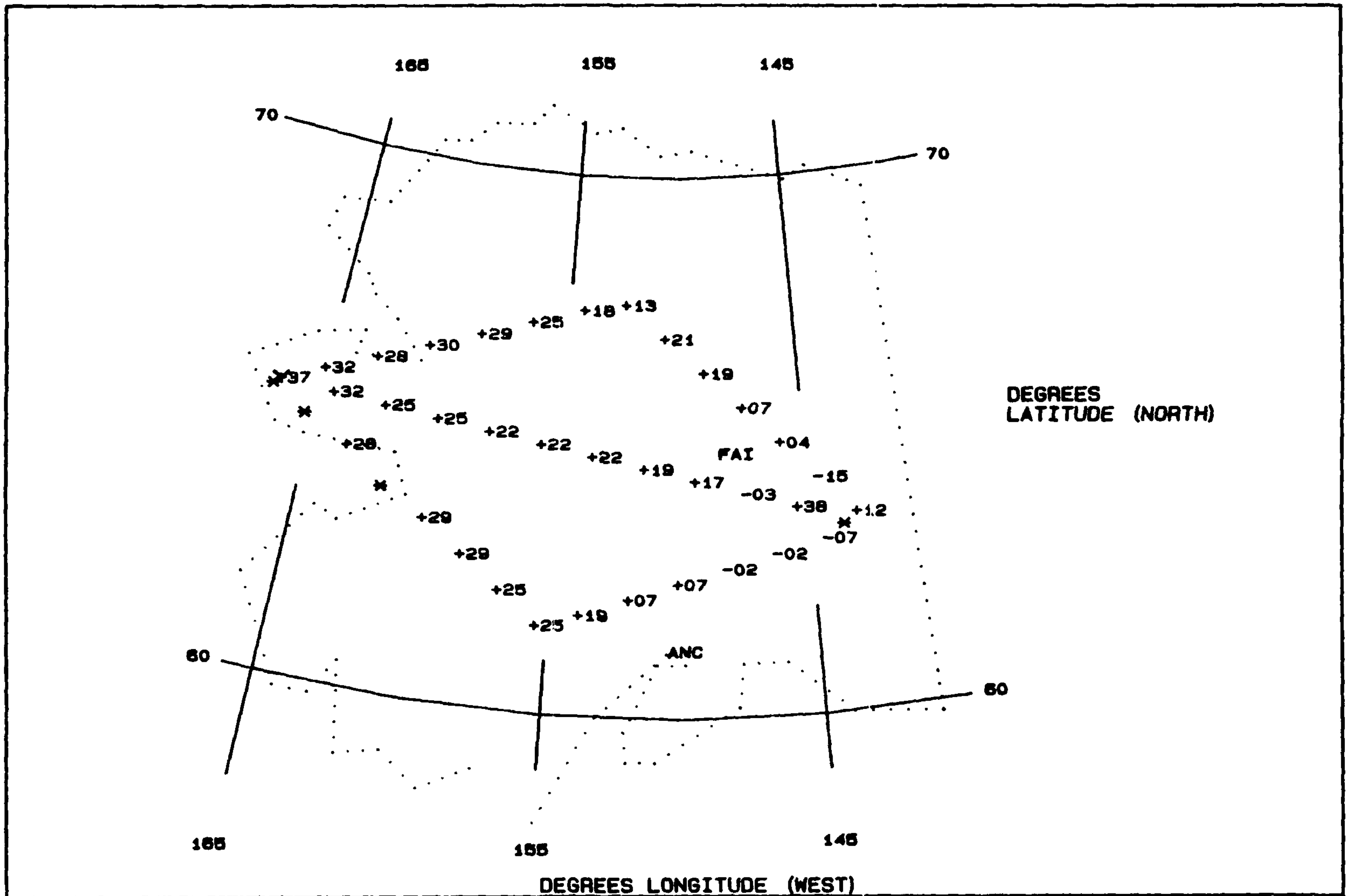
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #2
STATION: 9990 Y

FAA TECHNICAL CENTER
LORAN C COVERAGE

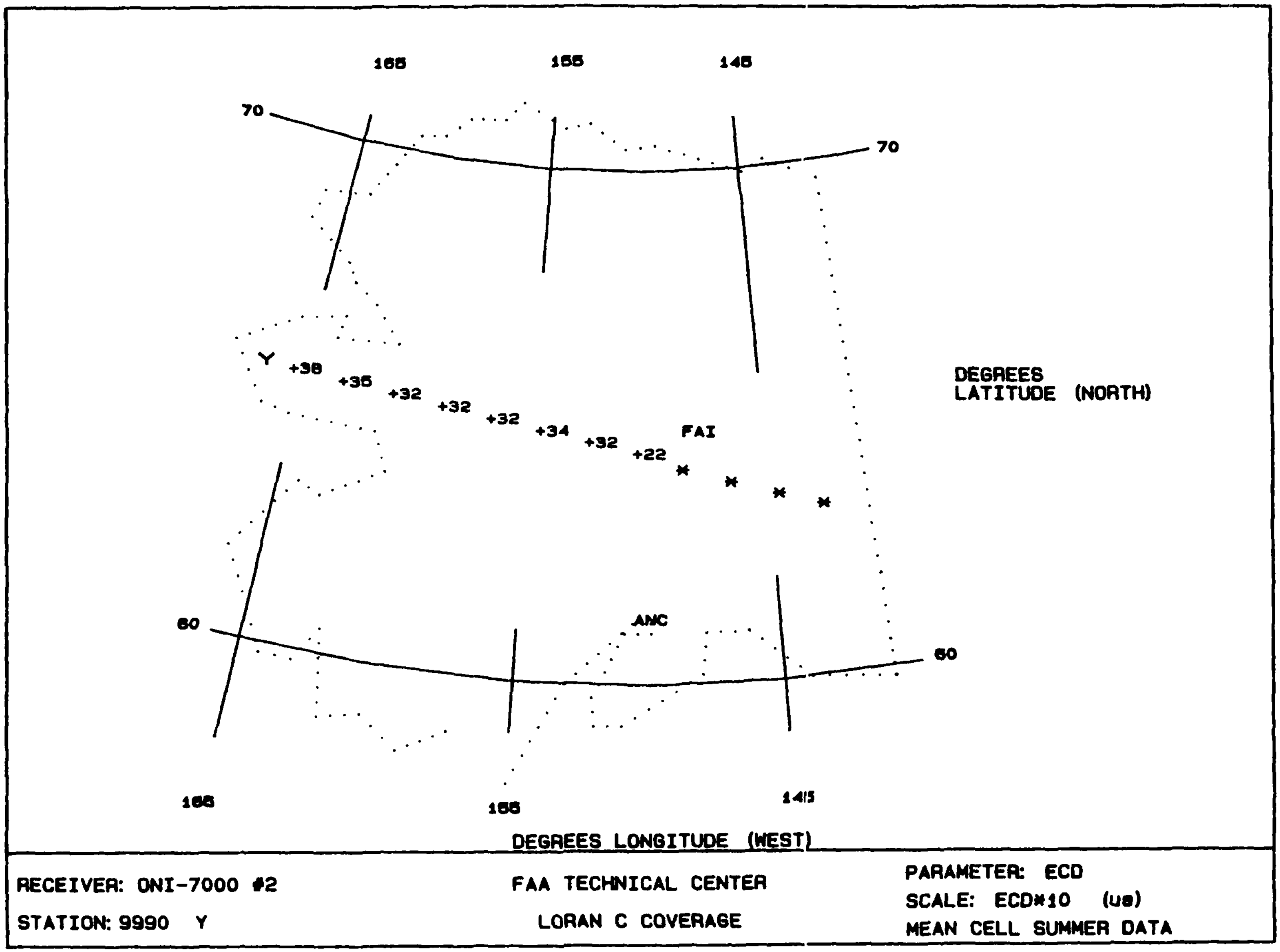
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL WINTER DATA



RECEIVER: ONI-7000 #2
STATION: 9990 Y

FAA TECHNICAL CENTER
LORAN C COVERAGE

PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA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155
145
70
70
DEGREES
LATITUDE (NORTH)
Y
+38
+35
+32
+32
+32
+34
+32
+22
FAI
ANC
60
60
165
155
145
DEGREES LONGITUDE (WEST)
RECEIVER: ONI-7000 #2
STATION: 9990 Y
FAA TECHNICAL CENTER
LORAN C COVERAGE
PARAMETER: ECD
SCALE: ECD*10 (us)
MEAN CELL SUMMER DATA

DATE
FILMED
3 8